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The frustrations of digital fabrication: an auto/ethnographic exploration of '3D Making' in school

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The frustrations of digital fabrication: An auto/ethnographic exploration of the realities of '3D Making' in school

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Abstract: Following initial educational enthusiasms for 'Making' technologies and the 'Maker Movement', increasing numbers of students are now using digital fabrication programs and equipment in school. Given the current lack of empirical research exploring the realities of Making as a school activity, this paper presents an in-depth auto/ethnographic account of 3D printing—currently, one of the most popular Maker technologies in schools. Investigating the case of an 8-week Year 9 design project, this paper seeks to broaden understandings of how 3D printing technologies and practices are shaping "what counts" as learning within contemporary school settings. In particular, this research focuses on the experiences of Making within a school context; what is learned through these experiences; and how the process of Making in school feels. This paper highlights three key issues that have been marginalised to date in discussions of Making in schools: (1) lack of pragmatic engagement, (2) affective labour of failing; and (3) mediated alienation.

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INTRODUCTION

For the past 40 years or so, schools have been expected to incorporate the latest digital technologies. Presently, 'Making' technologies and the 'Maker Movement' are heralded as having potential within K-12 schools to enhance opportunities for students to engage with STEM subjects, develop creative skills, and engage in collaborative forms of learning (Martin, 2015; FabLearn, 2015; Vandevelde *et al.*, 2015). The Maker Movement is a diverse global community of designers, art and craftspeople, programmers, hackers, and engineers. The basic idea of Making emerges from traditional hobbies and crafts including - but not limited to - sewing, woodworking, metalworking, and electronics. These activities have been rehabilitated in recent years as a result of the development of digital fabrication tools and online communities where individuals and groups can share ideas and designs, and build on various projects. According to Dale Dougherty (2013), founder of *MAKE* magazine and creator of Maker Faire, the Maker community is a group of individuals who approach things in novel ways and might "spark" a new generation of scientists, engineers, and Makers. The former editor in Chief of *Wired* magazine, Chris Anderson (2012), has hailed the Maker Movement as the "new industrial revolution". All told, Making has garnered burgeoning media coverage, stimulated federal and state policy making, and has attracted significant commercial and philanthropic investments.

Academic commentators have begun to consider the pedagogical impacts of the Maker movement on education and learning, arguing that bringing such technologies and practices into the context of formal schooling presents opportunities to redefine "what counts as learning, as a learner, and as a learning environment" (Halverson & Sheridan, 2014, p. 503). Martin (2015), for example, claims that Making holds the promise to bring playful yet challenging engineering and design projects into school. Kafai *et al.* (2014, p. 535) argue that Maker activities alter the nature of young people's engagement with technology – "serv[ing] to disrupt typical notions about *how* and *who* can learn and create with computers". Others have observed the potential to engage growing numbers of women with new approaches to designing and engineering technology (Buechley & Hill, 2010).

One of the most heralded, and certainly most prominent, Maker technologies currently being introduced into schools is the 3D Printer. 3D printing has been celebrated as an innovative way of connecting design practices with science, technology, engineering, mathematics, and design subjects (White House, 2014; UK Department for Education, 2013). The falling cost and increasing sophistication of 3D printing devices and materials have hastened their acceptance in schools. Yet, while there is a growing discussion of the *promises* that 3D printing and 3D Making processes hold for K-12 education, there is a notable lack of empirical research to explore and evaluate the *realities* of Making as a school activity.

This paper responds to Halverson and Sheridan's (2014, p. 503) call to research the Maker Movement "with subtlety rather than simply asking whether Making is 'good' or 'bad' for learners and instructional environments". In particular, the paper seeks to broaden understandings of how 3D printing technologies and practices are beginning to shape and

change "what counts" as learning within the contemporary school setting. What follows is an inquiry into the technical, institutional and (above all) individual dimensions of 3D Making in a school setting. The questions that guide this research include:

• What are students' experiences of 3D printing within a school context?
• What do students learn through these experiences?
• How does the process of Making in school feel (e.g., motivating, challenging, etc.)?

METHODOLOGY

These questions are explored primarily through an auto-ethnographic research approach – i.e. "self-narrative that critiques the situatedness of self with others in social contexts ... the intentional and critically reflexive connection of this narrative to larger social issues, to the politics, pleasure, and pain of other people" (Spry, 2001, p. 498). Auto-ethnography has been referred to as "action research for the individual" (Ellis & Bochner, 2000, p. 754). Similar to other forms of qualitative research, objects of auto-ethnographic analysis can include "short stories, poetry, fiction, novels, photographic essays, personal essays, journals, fragmented and layered writing, and social science prose" (*ibid*. p. 739). The auto-ethnographer's use of artefacts, metaphor, and psychological and literal journeys, for example, are some techniques for reflecting on, interpreting, and conveying a "patchwork of feelings, experiences, emotions, and behaviours that portray a more complete view of … life" (Muncey, 2005, p. 10). In the case of my own research: life in a digital school.

In order to obtain such insights as an ethnographic researcher embedding in a high school for 25 months, I participated in completing the main activity for a Year 9 woodworking course at *Lakeside High School[1]* in Melbourne (Table 1), Australia. Thus, as Van Maanen (1988) might argue, this work can be best understood as a "confessional tale" of my fieldwork experiences of Making as an academic researcher assuming the temporary role of student participant.

	School background	Location
Lakeside	102 Teaching staff, 27 non-teaching staff 1190 students 30% students language other than English 65% students progress to university	Inner-city suburbs, Melbourne Median household income: $2200/weekly 3.7% unemployed

Table 1. Description of *Lakeside High School*

Following the ethnographic tradition, this paper does not simply present an evocative personal narrative (Denzin, 1997). Rather, it is analytic inasmuch as the author was "a full member in the research group or setting … visible as such a member in the researcher's published texts, and … committed to an analytic research agenda focused on improving theoretical understandings" (Anderson, 2006, p. 375). The methodological benefits of such a participatory approach to researching Making within a school context were considerable. For example, I had the extended opportunity to experience the realities of participating in the class activity – especially in terms of obtaining an "embodied understanding" (Hakken, 1999,

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[1] All names in this paper are pseudonyms.

p. 39) of Making practices. Similar to the 25 students who were new to 3D printing (21 boys and 4 girls), my own lack of familiarity with the subject matter and technology allowed me to engage with the task as a new student and researcher. Hence, the process of "doing" allowed for direct experience of the psycho-social and affective practices of learning in a school community, similar to the extended engagements of the students in the activities.

This research project is one component of a larger in-depth qualitative study of digital technology use in three Australian secondary schools. The ongoing, larger ethnographic study employs approaches along a continuum from non-participatory observations through to participation in some classes. Unstructured observations and field notes were made in and around the school, and, where appropriate, data in the form of photographs, videos, and sound recordings were collected to expand the scope of investigations beyond the spoken and written word. As well as large-scale surveys and records of hundreds of hours of corridor/classroom conversations and exchanges with students and staff, semi-structured interviews were conducted with teachers, administration, and ancillary staff.

Drawing on thematic analysis of the corpus of data relevant to this study, and structured initially by the *a priori* themes of the three research questions described above, this paper will now explore the ways in which 3D printing was experienced by both students and myself as participants in the woodworking class at *Lakeside High School*.

FINDINGS

The next four sub-sections of the paper provide a chronological account of my experiences as the participant researcher and student in the Making classroom. I have punctuated my personal experiences with student / teacher perspectives in the hope of offering a more comprehensive account of 3D printing in a formal school context. I have divided my inquiry into four themes/stages, namely: *i) Research and Idea*; *ii) Design*; *iii) Production*; and *iv) Evaluation*.

i) Research and idea

Week 1 – 'In school'

Lakeside High School was located in the city of Melbourne, Australia and had a total enrolment of 1190 students. The majority of the students, teachers, and management were white and primarily middle-class. While gender representation was more or less evenly distributed, the participation of girls in traditionally male-oriented subjects was varied. For instance, more girls chose to participate in woodworking and metalworking than the information technology classes.

Unlike the majority of the buildings on the school grounds, the basic structure of the school's woodworking spaces remained unchanged from the 1950s. The main woodworking room was home to a mix of old and new technologies, including a recently purchased 3D printer that was proving to be a novel attraction with many students. During my ethnographic fieldwork in *Lakeside*, I was invited to observe (and then participate in) weekly Year 9 woodworking classes run by Mr. Smith, a 49 year old senior teacher, now into his twenty-fifth year at the school. Mr. Smith had become a key source of data during my first months in the school. In addition, he was also the catalyst for the introduction of 3D printers into the school's

curriculum, thus providing a flagship example of digital technology the principal had pointed out on my preliminary visit to the school.

Design and production have always been professional interests for Mr. Smith. Beginning as a passion project about four years ago, he researched the processes of 3D printing and decided to take professional development courses at a local university in order to understand the technology. While not familiar with the 'Maker Movement' as a cultural concept, he was a proponent of DIY activities in school and at home. As Mr. Smith saw it, 3D printing projects had the capacity to engage a diverse array of students, encourage the development of psychomotor capacities, including the acquisition of skills in mathematics, physics, and industrial design (Fieldnotes - 14 May, 2015).

My participation in *Lakeside's* 3D printing project began in the second week of Term 2. Classes had just commenced. It was noted that students were seated in groups of two and three at their desks, sketching preliminary designs for a racing car they would have to build by the end of term. Girls and boys had already self-segregated. The students were mostly focused on their own work, chatting with one another about designs. Occasionally, they would go off topic, but nothing overly disruptive. They appeared to be enjoying their classroom work which was deemed evident of their commitment to the task.

Mr. Smith provided me with an outline of the plan for the term. Students could choose to build one of two types of cars: a fast car, or a car that could bear a lot of weight. They also had the option to build their cars from wood or to 3D print them. When their respective building projects were completed, there would be a car race to test the machines under set conditions (part of the course evaluation). Students were instructed to start researching how to design a car before making preliminary pencil sketches. Mr. Smith expected them to put in at least ten hours of online research in order to achieve a good understanding of how they would proceed with the project. The next step was computer assisted design (CAD): drawing formal schematics before producing the vehicle using the 3D printer.

At this point I had planned to observe the class from a distance. I interviewed two boys about their work and asked them to explain what issues they would have to take into consideration when producing their cars. Both of them answered "aerodynamics". I also asked them what was influencing their choice of car design. The first boy (Jeffrey) said he had looked on the internet and found designs of cars that appealed to him. When he had settled on a design he approached the teacher for advice on how to "tweak" the vehicle. The second boy (Rohan) had simply drawn a range of rough sketches he thought might work. He was unable to decide which one he preferred.

I moved to another group – girls, this time. Their desk was littered with paper, pencil cases, pencils, rulers, and a mobile phone. We talked briefly about car designs. One of the girls (Shani) had chosen to design her car like a triangle. The reason: it would move faster because of "aerodynamics". When queried, neither girls nor boys knew what "aerodynamics" entailed. Another girl (Zara) was designing her car like a cereal box. Her aim was to win the heavy-weight competition. The third girl's (Jasmin) design was somewhere in between the other two. I asked them what materials they planned to use to construct their cars. They said they were thinking about making their cars from wood rather than 3D print them. Their reasoning: they would have more control over cutting out the design when using wood, whereas the 3D printer would not allow them to make changes mid-print. I then asked what they thought about the mathematics required for the CAD process. Jasmin said it was easy.

The other two disagreed and bemoaned that it was "a lot of work".

I returned to Mr. Smith, and we had further discussions about the class project. At this meeting, I expressed an interest in participating in the activity. As a researcher, I thought 'doing' the activity would allow me to better understand the thinking processes students used to work through the course, thus enabling the researcher to experience the highs, lows, and frustrations of problem solving. The car, as an artefact for study, could also be considered as a possible representation of how digital schooling in contemporary society had evolved. By examining the stages of making this artefact, I hoped to gain insights into the various facets that comprised a school-based 'Maker Space'. Briefly, Maker Spaces are Do-It-Yourself (DIY) communities, both online and offline, where individuals can invent, design, create, and learn (e.g., libraries, classrooms, makerspace.com). Mr. Smith was happy for me to participate and handed me a workbook. At the end of the term, my project would be assessed along with the other students. What follows, are the statements of the main assessment criteria for the project:

> ***The task****: Design and manufacture an electronic car that is functional, accurate, and visually appealing.*
> ***Function****: Car must travel 20 metres.*
> ***Time****: 7 weeks to produce.*
> ***Cost****: Not exceeding a budget of $20 to produce.*
> ***Design criteria****: Should be in colour and wood or 3D (using basic sketching techniques).*
> *Components can be designed using SketchUp (CAD program).*
> ***Product criteria****: Must use 3 of the main processes:*
> • *Measuring and marking out*
> • *Sawing and/or cutting*
> • *Shaping and/or forming*
> • *Joining*
> • *Sanding and/or finishing*
> ***Size criteria****: Separate components must be no larger than 120mm x 120mm x 120mm.*
> ***Materials criteria****: Any of the following – balsa wood, 3D printed resin, glue, metal, and acrylic sheet.*

Week 2 - 'Preliminaries'

I scoured the internet for ideas on how I might build a 3D printed car. After many hours, I managed to complete the final sketches. I selected a car that looked like a machine from the movie *Tron* (Figure 1). However, after speaking with a male student (Aidan) who was convinced that my car would be impossible to print, I wondered if I was being overly optimistic. I settled on a model that I assumed would be easy to construct.
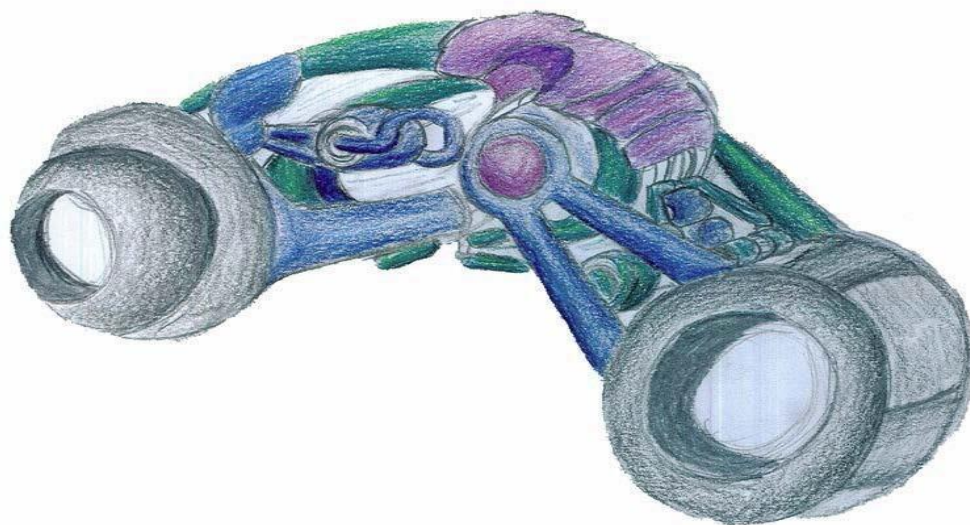
Figure 1. An unprintable design

Today's lesson was arduous inasmuch as I spent the entire class time learning how to use *Google SketchUp*, the CAD program that students were required to use when designing their cars. A male student (Michael) helpfully walked me through the program which seemed easy enough to understand. Included in the process of design and construction was an assessment rubric that students could refer to as a formative evaluation tool. I also decided to refer to the criteria embedded in the rubric to guide my work. The car would be evaluated according to research and design criteria, as well criteria related to production, functionality, and aesthetic appeal of the vehicle.

ii) Design

Week 3 - 'Frustrations in 3D'

By the time I reached the design stage, I had been attending the woodworking class for three weeks - observing and interviewing class members, as well as working on sketches of my vehicle both in-class and at home. Approximately half of the students had finished their design on *SketchUp*. Two girls had their components already printed and were assembling their cars. I settled down at what one student had christened my "usual spot" and fumbled my way through *SketchUp*. After a few unsuccessful attempts at designing a base for my car, I found myself getting frustrated with the CAD process. I turned to a student (Michael) for help. We conducted relevant measurements together and commenced the initial stages of designing my car on the computer. By the end of our *SketchUp* session he had helped me produce two parts for my car which, much to my dismay, looked like a brick. This experience enabled me to understand that there may be a considerable disconnect between conceptualising a product and its ultimate material existence.

I would now have to elaborate on the basics. The challenge here was with scale and measurements, which are not my strengths. I took more time working on my CAD design until I decided to take a break. I walked around the room looking at what other students were

doing. There were some impressive creations taking place. Toward the end of the lesson, Mr. Smith demonstrated how to insert the motor into a car (an important intervention by the teacher). He explained the need for building a block-shaped casing that would house the motor. He also showed us how to test that the motor worked. He then said he would provide a demonstration on Wednesday for students to become familiar with soldering, and how it should be practised safely. For the students who had their cars printed, they could decorate it with the Doodle Pen – a 3D wand that used plastic filament to produce designs on artefacts.

There was a group of girls waiting for their cars to print, so they were occupying themselves with the Doodle Pen. One of them was printing out a pair of bright pink spectacles. Another girl came along and changed the colour to green. She, too, doodled herself a pair of glasses. They donned their spectacles and asked me if I wanted to try out the Doodle Pen. They showed me how to use the gadget. It was a matter of pressing down hard on the pen, proceeding slowly, and waiting for the plastic to dry. The process was similar to that of using a glue gun. A third girl took the pen and doodled herself a pair of 'hipster' style glasses. The girls then took selfies with their new glasses on. While most of the boys were doing their work, or playing with cars that had been printed, one group was play-fighting as they waited for their cars to print. Mr. Smith noticed them acting up and reprimanded them. I went back to mostly aimlessly fiddling around with *SketchUp*.

Week 4 – 'The trouble with wheels'

There were quite a few boys absent from class today. The remaining students, in small groups, were engaged in their work. Some were soldering their cars. Others were filing edges to make the vehicle smoother. About half the class was still working on design in the CAD program which lessened my anxiety about the time I had been taking to do the task. Mr. Smith was helping a student measure wheels for his car. I asked Mr. Smith for some pointers and he responded in the affirmative. As I waited for him I initiated a conversation with two boys who were at the soldering table. One of them (Daniel) had opted out of 3D printing and had made his car from wood. He was soldering wires to his battery pack. With conviction, he told me the secret to soldering was "steady hands". His father was well-versed in such activities and had taught him what he knows. He then proceeded to show me step-by-step how to solder. When he was finished I spoke to the other student (Carl) who was attaching wheels to his car. I had been having trouble making my own wheels and I asked him how he had made his. Apparently, Mr. Smith had emailed students a file for making the wheels, so that it would be quicker to complete what was an already challenging task. This not only indicated the teacher's concern that students must complete tasks in the limited time available, but also that he was providing much-needed support to students who might not be as capable with the CAD program as others.

I set up my laptop in order to design my car but I soon encountered more problems. Now I could not figure out how to make curved edges. I found the student (Michael) who had been showing me how to use *SketchUp* and I asked for his help. By now I was resigned to asking students for help. Michael showed me what to do, making the task look easy. Mr. Smith stopped by to help me with the wheels. He showed me how to do various things I should have known how to do if I had watched the tutorials properly. Hence, this experience highlighted that regardless of the autonomous learning espoused by proponents of the Maker Movement, teachers still had a certain responsibility for modelling various processes and techniques, when and where required. After hours of labouring, I discovered that my car was too big to print out in one attempt. As such, the best option was to rescale the model. This meant that I

would have to resize wheels and other component parts which would throw out my measurements. I started to grumble to myself. What was I thinking when I took on this task?

I soon realised I also needed to use *SketchUp* to rotate the design of my wheels on the screen. While I knew what the *rotate* tool looked like, I could not figure out how to use it. Every time I tried, my wheels would end up in the oddest positions. At this point I was too embarrassed to ask the teacher for assistance again. My solution? *YouTube*. It did not take me long to find a helpful tutorial on the *rotate* tool. My attention span got me through half of the clip – just enough for me to get started. By the time I had fully figured out how to rotate, my head was pounding, so I decided to take a break from my car. I wandered off to a table where two girls were cutting apart their vehicles. One of them (Shani) had a car that was going to be the biggest in the class. During the initial design phase, she had not realised how big it would be as she could not grasp measurement and scaling properly. Her inability to grasp basic mathematics demonstrated that it was necessary for the classroom teacher to monitor all aspects of the learning processes and strategies. By the time her car was printed it would have taken 14 hours. Mr. Smith called out from across the room: "Your car may not be the fastest but it's definitely going to be the Rolls Royce of the class!"

The second girl (Zara) also had difficulty with scaling and measurement. She had originally wanted a car that would win the heavy-weight competition, but her intended car did not print out according to plan. She told me she ended up making a simpler design. Equipped with thick safety gloves, she was cutting excess edges off her car with a utility knife. She reckoned this was better than going back into *SketchUp*, rescaling, and printing out again. By the end of that class session, I had made a design that was starting to resemble a car. At this point, I would be happy as long as it could run the race.

Week 5 – *'Almost there'*

Many students had finished their cars and were play-racing against each other as they waited for the rest of the class to finish. Mr. Smith was helping one of the male students with his car because the wheels were not aligning properly. In addition, there was a table in the corner of the room with some of the finished products on display. I set up my computer and headed over to the teacher's desk. He mentioned the car race was on next Wednesday and asked if I was ready. I had to be honest: "not yet."

I spotted Daniel, the student who had built a wooden car. I asked if I could take a picture of his car and for him to explain how he had made his vehicle – it was the only wooden car in the room. I also asked him why he had chosen wood over 3D printed plastic. He said he didn't like the mathematics involved with *SketchUp*, so he preferred to do it all on paper rather than on a computer. It seemed that both boys and girls disliked the mathematics component of the activity.

I then sat down next to Mr. Smith who told me that much of the classwork had to be rushed. He wished they had more time to work on the projects and he indicated that three more lessons would have sufficed. I asked him if he was planning on entering a car into the race himself. He said yes and showed me his three impressively designed and constructed race cars. I spent the remainder of the lesson working on *SketchUp*.

Week 6 - *'A humbling experience'*

When I saw Mr. Smith that morning, he asked me how my car design was going. My response (sheepishly): "It's not". Unintentionally rubbing salt into my wound, he showed me examples of student work, ranging from basic drawings to *SketchUp* designs and prototypes. After seeing the sketch of a truck and how it translated into a CAD design, I started to worry more about my car ... I had to improve my game. And I had to do it fast. The more I examined the *SketchUp* drawings of these students, the more I wondered whether or not age made a difference when it came to the speed at which an individual could grasp digital technology processes and related information. Surely not? I had spent several days trying to understand the program. The 13 year old student who had created the design for the truck told me he spent three lessons on it. What was I doing wrong?

I left the school that day with a bruised ego. This problem was proving to be a humbling experience. In an effort to work through my 3D printing challenges, I decided to elicit a little help from my friends. Fortunately, back at the university, I worked with a 3D printing hobbyist who was happy to help me figure out what car parts I would have to print. He explained that a basic aspect to this task was measuring and scaling, neither of which I had bothered to do too much thus far. I now realised there could be no more cutting corners with my project. Everything had to be precise otherwise the printed car components would not align and/or fit properly.

I locked myself away in my university office, and found a pencil, ruler, eraser, and paper. One of the first things I had to do was draw a compartment for the motor. I had nothing I could use to construct a circle, so I improvised: the lid of my spectacles cleaner pump spray served the purpose nicely. Immersed in lines and numbers, another two hours passed before I realised that my car was too big. I wanted to bang my head on my desk. How did students do this day in day out? I noticed it was getting dark outside. Time to go home. At home I tried again. By the time I had a sketch that appeared to be satisfactory, I loaded *SketchUp* on my laptop, scrapped my first attempt, and drew another. By the end of the night I had managed to design a suitable base for the vehicle. For now, I was mentally drained. The rest of the car would have to wait until tomorrow.

iii) Production

Week 7 - *'Putting the pieces together'*

Given that I had one week to get my car printed and running, I was relieved when my university colleague suggested I print out my car on his 3D printer. Armed with my *SketchUp* file I was ready to go, until I discovered that all the work I had put into the car so far was for nought – the design could not be printed successfully. Apparently, the engine covering did not have depth, meaning that I would have to pull the structure apart and redesign. While I'm not prone to tantrums, I was ready to punch a hole in the wall. This experience was forcing me through an array of strong emotions, ranging from curiosity to perseverance, to demotivation and frustration. What was next? It was back to the drawing board - my 3D printing mantra.

The first thing I needed to do was split the base from the top in *SketchUp* as the top of the car was useless (Figure 2). This was done with relative ease. The next crucial step was to construct axles and wheels and connect the motor casing to the bottom of the car. This *SketchUp* design process took another eight hours to complete. By the time the designs were finalised, I decided I would not make the cowling with the 3D printer. My reasoning? I was unwilling to spend more time on a project I had already invested a lot of time and energy into. Hence, I would have to think carefully about alternative ways to design an upper casing for my car.
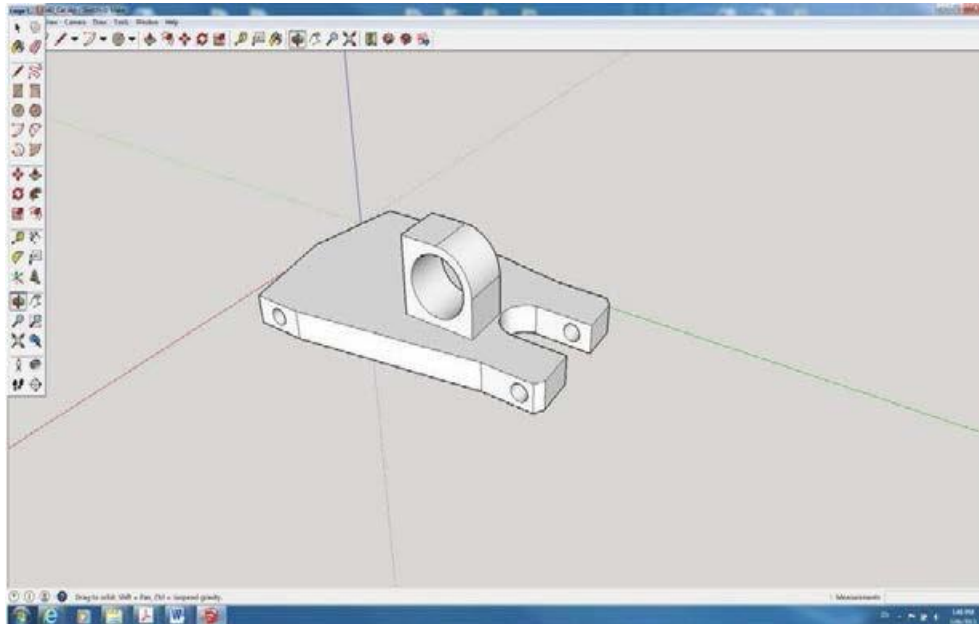

Figure 2. Working in *SketchUp*

The next day was printing day. My first print was a 'fail'. After one and a half hours, the printer had not yet produced a base for the car that was thick enough. After two more hours, the wheels, axles, and motor casing were finally completed. Now that I had the main parts of the car printed out, I had to figure out how to connect the circuit consisting of a motor, battery pack, and switch. I searched online but could not find anything useful. I then remembered the soldering clip I had asked a student to film during one of the classes, so I referred to that resource. By the end of the clip, I had worked out how to get all components of the circuit connected. Equipped with a box of tools, I was now ready to assemble the pieces of my car.

Getting the motor into the casing was no easy task as it was a snug fit. Once there, however, I realised that the elastic band running from the motor to the wheel would not align properly. This meant that I had to pull out the motor, but it would not come out of the casing. So I had to break the motor to extract it from the casing. Fortunately, my colleague had a spare motor at hand. The process used this time was to pare down the inside of the casing to fit the motor in without it getting stuck in the wrong position. I had to use a utility knife, gloves, and glasses for safety. The tools for paring the casing and safety precautions used, are shown in Figure 3.

Figure 3. Manual adjustments

During these processes, I found myself improvising on occasions. I discovered that the axles did not fit neatly into the holes in the base of the car. Like many of the students in woodworking class, going back to *SketchUp* and redesigning was not something I was prepared to do. My first option? Use superglue to lodge the axles firmly into the base. While I managed to glue the wheels in place, I also accidentally superglued my fingers together. Upon seeing the mess I had made on his desk, my colleague suggested sticky tape wrapped around the car part, which provided an effective solution to the structural problems. Hopefully the tape would hold.

Soldering was also an impossibility as I no longer had direct access to the tools I needed to complete the task, so sticky tape came in handy - again - to keep the wiring together. Provided the motor did not heat up too much, the tape would not melt. All I needed to do was get the car to the finish line, then it could fall apart … or blow up for all that I cared. When I had finally assembled the car, we completed a test run. It was exciting to see the machine function. The next step would be to work on the vehicle's aesthetic components.

Week 7 – 'Post-printing'

I went to the local art supply store yesterday with the aim of finding materials I could use to build an upper casing for my car. I had decided that the end product was going to be as gaudy as possible, as my aim was to amuse the students if nothing else. Mr. Smith had informed me there would be an additional race day category: "The Sexiest Car". I figured if my car flopped in the race, it may as well be memorable in the process. So I found bright pink glitter cardboard, bedazzling gems, borders, and skull and bones cut-outs. Gluing the cardboard down was the first task that I did. The next step was to glue the borders around the car base. The bedazzling gems lined the motor casing and I was off to a good start. I enjoyed this hands-on part of the project. For me, using my hands to manipulate the machine felt more like Making.

Given that the battery pack kept moving around, I had to glue that component down too. Once the pack was set, I could fiddle around with other components like decorating with skull and bones and adding a cover to hide the batteries. There was a lot of playing around

with parts/pieces to make them fit together, but nothing that could not be resolved within a couple of hours.

Measuring did not have to be precise as in *SketchUp*. I felt like there was more spontaneity which allowed me to test what car parts would look like in a shorter amount of time than what had occurred in the CAD program. While experimenting in CAD was possible, I would have to print out the product (which could take hours) before I knew whether or not the artefact worked/looked good – there was no spontaneous testing. In contrast, playing with tangible objects in 'real time' made creating less of a laborious chore. My car (Figure 4) was finally ready for the big race.
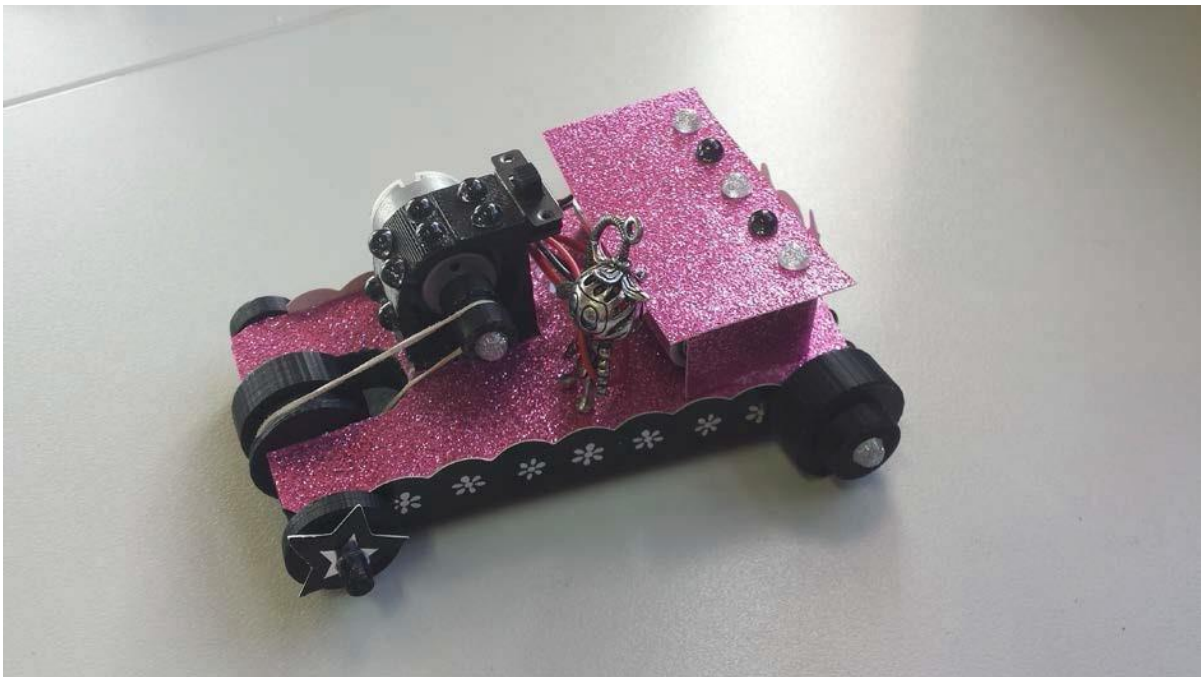

Figure 4. The finished product

iv) Evaluation

Week 8 – 'Race day'
I had stayed up late last night pre-testing my vehicle. It was running well, zooming up and down my living room floor with no problems. I put it in a box to keep it safe and collected the video camera as I walked out the door. I wanted to capture footage of the race. When I arrived at the school, I was about half an hour early. Mr. Smith told me he had set up a race track in one of the main buildings but would start the students in the woodworking room just in case they needed to "tweak" their cars. He had put up a list of competitors who had entered each category. I would be racing against Mr. Smith. The students would race each other.

To my left there was a workstation full of unfinished cars. These machines were categorised as "Not-Working" so automatically gained entry into the "Sexiest Car" category. Mr. Smith mentioned that many of the students had not finished their cars largely because they had lost three lessons for various reasons (e.g., public holiday, teacher training, excursions). As 3D

printing was work intensive, the loss of time had an impact on students' ability to satisfactorily finish their respective projects. They would not be penalised for this.

Mr. Smith was excited to see my car and eager to watch it run. I was happy that he had so much enthusiasm. I flipped on the switch … Nothing. I fiddled around with the switch again. Still nothing. For the life of me, I could not figure out what had happened. It had been working well last night! I flipped the switch back and forth, messed around with the wiring – maybe the wires had come loose? I even changed the batteries, but whatever I did would not work. I assumed Mr. Smith could see my frustration as he told me not to panic. It might just be a soldering problem. We would try to fix it before the students arrived.

He quickly started up the soldering iron and began fusing wires together. We waited for the wiring to cool down and I flipped the switch again. Although the machine was now getting some power from the engine, the motor was running poorly and would not move past a few seconds of rotation. I pulled the car apart to see if I could do something to make it operate effectively. I was in the process of doing this when the students came in – some of them were complaining about their cars not working. Many of the boys stopped at my desk and told me my car was "cool" – especially the bright pink, and the skull and bones. "So girly but tough" one of them (Aiden) said:

> *Luke: Cool looking car, Miss. Does it run?*
> *Me: Last night it was running, but for now I'm afraid it does not.*
> *Aiden: That sucks. Can you fix it?*
> *Me: I'm trying.*
> *Luke: It must be sabotage. Someone doesn't want you to race.*
> *Aiden: Or not enough pre-release testing, Miss. You must have made an Apple icar!*
> *Me: Yes, I must have … it's melting in my hands as we speak.*

Mr. Smith had the students sit down, took the attendance roll, and gave them 10 minutes to tidy up their cars. I soon realised that more than half the class had non-functioning cars. Many of the students scurried around trying to make their machines work. Time was not on their side. A lot of these cars looked impressive, but various reasons prevented them from working effectively, such as bad soldering, incorrect wiring, loose fitting and/or broken parts.

While I tried my best to fix my car, I eventually resigned myself to the fact that it would not be able to race. I would have to sit this one out and be the non-participant observer that I had initially intended to be. I was devastated – so many hours of work put into a little machine that was running perfectly the night before. Suddenly, for no apparent reason this morning it had given up. The experience drove home the point that there was an inevitable element of unpredictability and chance that went hand-in-hand with digital fabrication.

During the ten minute fix-it period, some students (all boys) expressed dismay with what was happening to them. One boy (Michael) whom I thought would win the race had a wheel crack in half and fall off. It was impossible to repair, thus preventing him from racing. Another student had wiring melt which resulted in his choice to take his car out of the race. Another car had a faulty switch. Someone else had a car with wheels that would not spin. As the ten minutes came to an end, there was an increased sense of frustration in the air. The students were bemoaning that they had spent most of the term designing and making a car that all of a sudden would not do anything. I could understand and empathise with their pain quite well.

We eventually made our way to the main building and seated ourselves around the makeshift race track. Mr. Smith had forgotten to bring the weights for the heavy-weight car race, so that particular category was scratched to the dismay of several students. Only six students out of the whole class ended up participating in the races. The others watched. The first two competitors were vying for the fastest car title: one girl (Jasmin) and one boy (Daniel). After the teacher's "Three, two, one…" the cars were off to the accompaniment of loud cheering and whistling. Within seconds, both cars had veered right and smashed into the side barrier. The race had to be paused as Mr. Smith re-arranged the barrier to allow the cars to go straight. After another "Three, two, one…" The cars were off again. This time the machines veered left and crashed into the wall. The teacher called out "Keep going". The students ran to their cars, put them straight again, and the cars sped toward the finish line. Jasmin's car won by a nose.

When the races were all over, we returned to the woodworking room where Mr. Smith debriefed the students and announced the winners. He awarded the "Fastest Car" category to Jasmin. As there was no heavy-weight car race, he gave a first place win for "Best All-Rounder" to another girl (Julia). He left the judging for the "Sexiest Car" category up to the class. The students who wanted to participate in this competition were asked to hold up their car for inspection. The class voted the most unattractive, box-like car, as the winner. Everyone had a good laugh. Once the prizes (cookies and chocolate) were distributed, Mr. Smith congratulated his students on their work. He explained that this was a challenging activity, and the fact that they were actually able to design and print a car at all (functional or not) was an achievement given it was their first attempt to undertake such an open-ended task. I could not have agreed more, especially after experiencing the design and production process first-hand. The end assessment result for me was: A+ for aesthetics and B for functionality.

DISCUSSION

So what did I learn from the various experiences? I now understand that 3D printing is hard work and laborious, and can be disappointing and/or frustrating. Digital Making projects require understanding and precision in science and mathematics, they also require trial and error, and perseverance. Notwithstanding these prerequisites, considerable time is required for such projects to come to fruition, including allocating space for pre-testing if there is an evaluation task as an end point of the overall activity. It would also be preferable if assessments could be conducted at regular stages by both teacher and students on the chance that products might fail prior to final evaluation.

In terms of the design process, it is all too easy to forget the importance of the fabrication of a prototype when designing and focus simply on a computer rendering of a design. However, a design is refined in the Making and ongoing return to the initial digital design idea, a point that was highlighted consistently through my [at times frustrating] experiences with 3D printing. As Wiener (1993, p. 37) indicates, when discussing inventions: "Besides the conditioning of new inventions by the ideas on which they depend, there is a further conditioning in terms of the materials and processes available". This is too frequently forgotten with digital design and ought to be at the forefront of discussions when Making in school in order to present students with realistic expectations of what being a Maker entails at a practical level.

Most important, however, are my critical reflections on what it means to be a student Maker in a formal school setting. I separate these reflections into three categories: 1) pragmatic engagement, 2) the affective labour of failing, and 3) mediated alienation, all of which speak to the relationship between Making and what it means to be a student in a digital age.

1. *Lack of pragmatic engagement*

What can be said about Making as a set of activities (Halverson & Sheridan, 2014)? In the case of my race car, these activities included research and conceptualising, designing the artefact on *SketchUp*, production, and evaluation. Making, according to the New York Hall of Science (2013), "fosters lifelong learning by encouraging learning by doing" (p. 2). Maker programs are seen to offer students who experience school as "unsatisfying, tedious and boring" an engaged setting (*ibid*, p. 2) where they can learn through hands-on approaches to class activities. Yet, in contrast to the discourse about Making as fun, engaging, and an antidote to the drudgery of schooling, the reality is that Making demands hard intellectual and challenging labour. From my own experience, this was remarkably similar to the intellectual labour demanded by traditional school tasks such as writing an essay.

If we conceive of Making as a digital activity, my experiences with 3D printing consisted mostly of laptop-based planning and design. The actual 3D printing component comprised a small portion of a CAD process that was protracted and challenging, not to mention tedious and repetitive. Similar to the students, I spent hours tweaking designs to gain the required mathematical precision so that my car stood a reasonable chance of being printed accurately. Yet even my printable design did fail, along with many other designs the students in the class had worked hard to generate. As a rough estimate, perhaps 90 per cent of my Making time was an intellectual endeavour grounded in numbers. The process of 'doing' occurred primarily on the computer rather than using my hands to measure, for example, the dimensions of wood or plastics, to cut and manipulate materials. This mainly involved using my mathematical knowledge to solve problems such as scaling and measurement, and using my hands to input data. Only toward the end of the term did I use my hands to connect the required wiring, and decorate the car when the basic framework had been printed.

It was evident that this constant intellectual demand was off-putting to the students who grew tired of the activity of Making because of the amount of mathematics required to successfully design a product on *SketchUp*. For example, one of the girls (Zara) in the class had such difficulty with scaling and measurement, that she opted eventually to cut apart and file down the excess portions of her car by hand, risking injury rather than going back into CAD. This sentiment was shared by both girls and boys to varying degrees. I, too, felt the same way after weeks of failed designs, eventually opting to improve the cowling of my car without the assistance of a computer.

It would seem, therefore, that there is nothing especially engaging, or fun, about digital fabrication in comparison to what traditional schooling activities can offer. Making, as enthusiasts would argue, allows educators to "reimagine schools and foster a mindset of creativity and innovation in educational settings" (Peppler & Bender, 2011, p. 22). Yet this seems to be a romanticised vision of something that is mainly distinguished from other creative activities in schools by virtue of its digital dimension. The reality is that the school curriculum ultimately shapes Making as an activity that hinges on scientific and mathematical knowhow.

Making, then, is not as engaging as some would argue. Rather, when Making is enacted in a school setting it becomes constrained by institutional requirements such as aims and objectives that target specific modes of intellectual development. In summary, my 3D printing experiences suggest that there is a considerable disconnect between conceptualising a product and its material existence (also noted in the students' activities). Moreover, the process of Making in schools is mostly an intellectual endeavour that does not start with the embodied experience of using tools in terms of pragmatic engagement. Instead, Making privileges a theoretical understanding of the artefact (as an object of substance consisting of mathematical and scientific properties) above 'doing' with one's hands. In this capacity, Making as digital fabrication is an intellectual endeavour first and foremost.

2. *Affective labour of failing*

My experiences also highlight the connection between Making and labour. As scholars have argued, digital labour is an extension of the concept of work, connecting technological advances to the notion of work as play (Fuchs, 2014). This specific mode of labour through socialising and play can be found in the discourse of Maker Culture with its celebration of play as a method of creating future innovators who will revolutionise the "manufacturing might" of Western cultures (Anderson, 2012). Dougherty (2013), for instance, argues that at the core of the emergence of the Maker Movement is "experimental play". He claims that the Maker mindset is a "growth mindset that encourages students to believe they can learn to do anything" (p. 10). From this perspective, the philosophy of Making is grounded on free choice, discovery, play, and rejects the language of weakness. Making, then, is playful which "begets experimentation, which leads to the development of conceptual knowledge and promotes adaptability in the face of challenges" (Martin, 2015, p. 37). These connotations of experimentation are attached to a celebration of failure within Maker discourse. For Martin, failures (whether big or small) have the ability to stimulate learning, "as they bump people out of routines and into a reflective mode that can prepare them to learn more" (*ibid*., p. 37).

Yet, underpinning Making as play and its valorisation of failure is an array of emotions that seem to be overlooked in the rhetoric of Making as a path to reimagining education. First of all, the celebration of failure does not necessarily fit with the performative realities of the school setting (Ball, 2000). Failure certainly does not fit well with overall curriculum aims and objectives, all of which students must meet in order to move through education and on to employment pathways. Secondly, in my experience, despite the teacher congratulating his students for the work they had produced (functional or not), failure was neither validated nor celebrated wholeheartedly by the classroom community. Most of my fellow Makers in Year 9 were up front about their disappointments and frustrations, resonating with Soep's (2014) claims that youth can experience the failures of Making as demoralising. These negative emotions were particularly evident during the end-of-project races when students expressed anger and dismay with what was happening to them. Students lamented the fact they had spent a term designing and making a car that all of a sudden could not do anything.

3. *Mediated alienation*

Another point of contention arising from the project is that of mediated alienation. It is argued that Making generally offers young people a significant voice in what and how they make things (Martin, 2015). From this perspective, Maker contexts that support autonomous action and the potential for young people to take control of their work are more motivating, and supportive of engagement, and nurture the development of identity and resourcefulness.

Making also has the potential to cut across gendered and socio-economic barriers to learning (Kafai *et al.,* 2014). In light of these claims, how might we understand the Maker Movement and its recent entry into school settings? How *is* the addition of Making to the curriculum reconfiguring education in terms of a student-centred experiences? What evidence was there from Mr. Smith's classes of Making as "fundamental to what it means to be human", or Making as an act that allows us "to feel whole" where the "things we make are like little pieces of us and seem to embody portions of our soul" (Hatch, 2014, p.11)?

As an outcome of my experiences of the 3D printing project, I found the design process to be a detached activity that privileged my thinking capacity over 'doing' or Making with my hands. Creating turned on the act of my engagement with a machine. In this respect, I felt a distinct alienation from the product I was making rather than any direct connection to the artefact. I felt little sense of being an autonomous and creative spirit. Instead, there were coded boundaries to autonomous action and to the freedom to express myself. Whatever structurally did not fit with the machine's ability to print accurately was rendered obsolete. Instead, what I could create was determined by coding and algorithms. As Galloway (2014) argues, "Protocol is synonymous with possibility [or lack of possibility] … protocol outlines the playing field for what can happen and where" (p. 204). As such, it was the protocol of the CAD software that managed my creativity and what I could and could not make. It was Google in the form of *SketchUp* that de/limited the possibilities for what I could and could not create. My labour in this setting was controlled by digital rules set by an external entity with the power to dictate how I was able to embody myself through what I made. Thus: "If one chooses to ignore a certain protocol, then it becomes impossible to communicate on that particular channel. No protocol. No connection" (*ibid*., p. 204).

While I eventually chose to engage with 'old fashioned' crafting to attend to the aesthetics of my car, many students did not. Most of them did not engage with the aesthetics of the task short of 3D Doodling their names on the cars or printing out parts in different colours. Rather, they seemed to be more concerned with functionality as their end goal – what the 3D printing assemblage would allow them to build as opposed to what they *really* wanted to build. Their creativity was constrained by a computer application. In a conversation with one of the male students (Olivier), I discovered it could sometimes take three to four prints for a structure to be printed correctly (i.e. with all its dimensions and parts accurate and intact). This, in itself, was enough for him to give up on his original design and simply do whatever was necessary to build a machine that worked, as long as what he built allowed him to pass the course. There was no emotional tie to the product being produced, no deep-seated soulful act that marked him, or I, as natural born Makers expressing our essential humanity through the art of Making. Rather, there was a detached 'doing' that occurred which fitted through necessity with the evaluation criteria. In this sense, I experienced 3D Making as a form of mediated alienation – where I was distanced from what I produced by a computer so that I never truly worked with my hands. I never truly had the autonomy to create what I wanted because the machine always mediated my capacity to produce and the form that the product took.

CONCLUSIONS

This paper marks an initial attempt to broaden understandings of how the Maker Movement, specifically 3D printing, impacts thinking and learning in a school setting. The questions that have guided this work are: What are the experiences of Making within a school context? (What did I do?); What was learned through this experience? (What/how did I learn?); and

How did the process of Making feel? (How did I feel?). Of course, Maker proponents might argue that my 3D printing experience was simply one dimension of Making and should not be taken as a generalisation of the entire movement in school. However, projects such as these *do provide* evidence of how Making is being lived in school contexts. When examined from this perspective, the practices of Making in school are very different to the practices of Maker spaces outside of formal schooling.

Above all, my findings lead me to suggest that while Making might serve as a way of democratising the classroom as a knowledge building community, it should not be accepted uncritically as a solution to reimagining schools. Rather, Making ought to be approached as a method of teaching and learning with the same pitfalls and obstacles that previous new digital technologies have brought into the school setting. As with any auto/ethnographic work, this paper has presented a set of very personal experiences and reflections. Further empirical studies are necessary in order to develop a critical understanding of how Making is enacted in different formal educational communities, how it is lived by both students and teachers, how it shapes teaching and learning processes, and what kinds of knowledges are privileged in such environments – "what counts" as learning. As such, the topic merits continued attention in order to develop robust understandings of the various possibilities and challenges the Maker Movement holds for K-12 education.

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