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Sew what? Introducing an engineering textile fabrication project

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ABSTRACT

CONTEXT

Practical experience in designing and building solutions to engineering problems is limited in scope in many Australasian engineering programs, due to scale, budget, availability of suitable spaces, equipment and technical staff. In this paper, we present a textile design project. This hands-on design and build technical project is cost and space efficient, can be taught on campus or remotely, and has many real-world applications.

PURPOSE

In engineering practice, sewing is used in many applications such as lifting slings, parachutes, shipping sails, automotive vibration and noise control, seat belts, carbon fibre layup, medical garments, and high-performance sporting garments. However, sewing is not commonly thought of as an engineering activity. This project sought to challenge that perception, and provide an opportunity for students to develop hands-on skills while addressing a real-world problem.

APPROACH

In 2021, students in a second year Mechanical and Aerospace engineering unit designed and fabricated textile masks with replaceable filter elements, and tested them to elements of the Australian P2 standard (AS/NZS1716:2012). Instruction was provided asynchronously through pre-recorded videos, and synchronously through video and in-person workshops. Students could utilise the on-campus equipment (sewing machines, overlockers and embroidery machines), use equipment available at home, or hand sew. Masks were chosen as an authentic, real-world design problem given students had experienced mask use firsthand due to the ongoing COVID-19 pandemic. Students had to think critically about mask design requirements in addition to the recommendations of the World Health Organisation.

OUTCOMES

At the conclusion of the testing phase, the majority of student fabricated masks passed the experimentally assessed elements of the P2 standard. Some students progressed from having never threaded a needle, to being able to confidently operate a sewing machine and construct their own designs. Students whose cultural background or traditional gender roles may not have encouraged them to sew were able to experience and enjoy creating their own textile prototypes.

CONCLUSIONS

The project allowed students to design and build functional, sewn prototypes and relate them back to a real-world contemporary problem. Students overcame their initial biases to expand their perception of engineering work.

KEYWORDS

Sewing, textiles, manufacturing, fabrication, design, hands-on skills

Introduction

In 2021, in response to the COVID-19 pandemic, we commenced redesigning and developing our second year Mechanical Engineering design subject for online and hybrid delivery. With many Engineering students offshore and in periodic quarantine and with the ongoing risk of further lockdowns, we needed to craft a design and build project with learning outcomes that could be met by remote students isolated at home with limited access to stereotypical engineering workshop facilities. Despite these challenges, we required students to develop hands-on design and manufacturing skills and experience a build project as a foundation for success in subsequent units in their program and their future work as engineers. The unit, MEC2402, Design 1, typically comprises a team-based open-ended design project responding to a given brief as the first unit in the 'design spine' of the Mechanical Engineering course.

We developed a novel mask design project, where students designed, fabricated and tested two masks - one primarily textiles based and one primarily non-textiles based. Masks were of critical importance at the time, as personal protective equipment (PPE) was in short supply and in high demand. Masks were familiar to all students, and the project gave the students a sense of agency in contributing positively to pandemic readiness in an otherwise uncertain time.

In this paper, we focus on the textiles mask and more broadly, the utility of and rationale for teaching engineering students to sew. Sewing is a useful construction technique used to fabricate many kinds of textile objects in industry, such as parachutes, airbags, and space suits. Most students coming into the subject had no experience with sewing, and many were reluctant to try due to their cultural and gender biases about sewing. Sewing is cheap and easily accessible - sewing machines start from $35, and hand sewing is very inexpensive. Sewing machines are also impressive feats of mechanical engineering in their own right.

As an authentic assessment, a brief of work was constructed for the students, and the teaching team presented themselves as the client - an automotive filter manufacturer who was looking to expand their market into PPE in response to the pandemic. Hypothetically, this company could produce filter element material capable of P2/N95 filtration performance when successfully incorporated into masks. Students were given free rein on what the design was to look like, and the only criteria was the wetted area of the filter material. Each team had to produce two masks, one of each type. Students were challenged to size their masks to fit their team members (to allow self testing) and also a medium-sized ISO-NIOSH digital head form (CDC, 2020). Strict COVID-19 protocols were designed and applied to prevent student teammates from exposing each other (and staff) to potential infection via fit and performance testing of their shared designs.

Teaching sewing using a hybrid approach was surprisingly effective. The students were provided with a playlist of instructional videos (some produced by the team, some crowd-sourced via youtube) to develop their knowledge about the technology before class, in their own time. During class, they could watch the demonstrator via close-up webcam footage. The project was equitable and accessible to all sewing skill levels. All remote students could use a sewing machine if they had one or source one (most were able to), or they could choose to hand sew their mask. The students were marked on a range of criteria covering the ability of their design to meet the brief, and its effectiveness against the P2 standard. They were not marked on how well they sewed, but rather the functionality of the finished mask.

Context

Textile fabrication in engineering practice

'Textile fabrication' is the term that we strategically chose to refer to the process of designing and manufacturing products using textiles as the medium. Sewing is just one possible process under this umbrella, which also incorporates pattern making, textile deconstruction (seam ripping) and the different styles of sewing beyond plain stitch process (i.e. overlocking, embroidery, cover stitching, 3D construction methods etc). Sewing is used in many engineering applications in industry, including lifting slings, parachutes, space suits, sails, inflatable robots, medical garments, and high-performance sportswear. Sewing is critical in automotive applications, in seating, headliner, boot liner, floor pan and side trim for vibration and noise reduction and for safety (airbags and seatbelts). Our clothes and soft furnishings are most commonly constructed using sewing.

Clearly, sewing is a vital engineering manufacturing method. However, what first convinced us to undertake this project was seeing students doing textile fabrication badly - glued vinyl headrests falling apart, tire covers not staying on, repairs to fabrics done with duct tape.

The project brief asked the students to comply with the Australian Standard AS/NZS 1716:2012 (2012). This standard specifies the requirements for respiratory protective devices that protect against substances that can be harmful if breathed. AS/NZS 1716-2012 was chosen as an appropriate standard because the filter material we were able to procure was successfully tested to this standard for particulate filtering and flow rate.

Sewing teaches engineering students valuable skills such as geometry, construction, shape manipulation (i.e. integrating curves into sewing is like designing ductwork intersections), 3D thinking and spatial awareness, and materials selection. Fabric and thread are cheap and readily available. Students can learn to use a sewing machine with a little instruction and some time to practise the skills required.

Teaching textile fabrication in engineering programs

While engineering work is required in the textiles industry, it is difficult to find references for teaching engineers to sew. This could be due to the lack of a local textiles industry; the emergence of E-textiles and smart wearables focusing on embedding technology rather than fabrication; the outdated attitude that engineers don't do the "dirty work" of making; or the perception of sewing as a craft or as gendered work.

One pattern we noticed in the literature was a multidisciplinary approach to teaching textiles in engineering programs, where designers and engineers work side-by-side for mutual benefit. Ehrmann (2018) noted that in their Textile Technologies course, "the broad range of interdisciplinary skills and topics leads to completely new ideas and solutions for diverse problems". Students completed textiles projects in areas such as carbon fibre car bodies, textile solar cells, and protective clothing for bikers. Salolainen et al. (2017) teamed designers and engineers to find that "by opening the world of engineering to design students and especially by exposing design methodologies and the visual research processes to engineering students, we can help collaborative teams to redo the future". Specifically, they teach their students research and concept development; printing, weaving and knitting; and photography and presentation.

The lack of a local textile manufacturing industry

In countries with a strong textile manufacturing industry, such as Pakistan and Turkey, degree programs in textile engineering are available, and the links between engineering and the textiles industry are strongly drawn. These engineering practices include design, testing, quality control and process optimisation (Nawab, 2016). Australia used to have a strong automotive textile industry. However, most manufacturers moved offshore with the demise of the automotive industry in Australia. A few specialist aftermarket manufacturers remain, but they are very small and are not significant employers of our engineering graduates.

E-textiles and smart wearables

There are many emerging examples of E-textiles and wearable technology in engineering curricula and STEM more broadly, particularly in medical and biomedical engineering (Samardzic & Sekulic, 2022), electronic engineering and computer science. These courses usually focus on embedding technology in wearable devices and prototyping those devices using various techniques such as 3D printing. Similarly, smart textiles are often used to engage girls with STEM in K-12 outreach activities (Reimann 2011). These courses tend to privilege functionality over construction and do not usually teach sewing as a fabrication technique.

Cultural and gender bias

Engineers don't get their hands dirty

There is a strong history of teaching textiles and sewing in high school design and technology courses and in engagement and outreach programs designed to build pathways to engineering - yet these fabrication techniques don't currently continue through to tertiary engineering programs. We predicted that some students might have a problem engaging in an engineering project that asked them to sew. Indeed several comments in the student evaluations (see Outcomes - Student perceptions in this paper) asserted that sewing was totally irrelevant to engineering, e.g. "instead of doing mechanics and robotics… students have to sew together shitty masks".

Engineers have been told for more than a century that they should get their hands dirty in order to truly understand manufacturing techniques in many disciplines, even specifically in textiles:

> *A textile chemist needs to be adept in engineering, to have a knowledge of machines, their principles of construction and operation… the prospective textile chemist should seek employment in a mill where he (sic) may have access to as wide an experience as possible. He should not be content to go into the mill laboratory (if there is one) and perform routine analyses merely; such work should be only a part of his functions. He should work out in the various departments of the mill, put on overalls and get his hands soiled, but acquire a knowledge of the practical manufacturing operations all through.* (Matthews, 1911)

However, in recent decades, many research-focussed universities moved away from teaching integrated applied design throughout their courses, instead focusing on teaching theory and technical skills separately. Even more recently, a resurgence in applied design teaching has partially been facilitated by the needs of industry for graduates with skills in new and more accessible prototyping techniques such as additive manufacturing. In the Engineering Futures: 2035 scoping study (Crosthwaite et al., 2019), "The majority of thought leaders anticipated that "team-based, hands-on student learning that responds to the needs of society and industry" would underpin the world's leading engineering programs in the decades to come."

The maker movement is gaining legitimacy in engineering circles as we return to prototyping. However, initial explorations with our own academic staff on the tools, processes and equipment required to 'make something' in their own practice yielded few results due to most senior researchers being far removed from the process of making. At a card sort activity conducted in 2018 to design our new engineering makerspace (Figure 1), there was much derision from engineering staff at the inclusion of sewing machines.

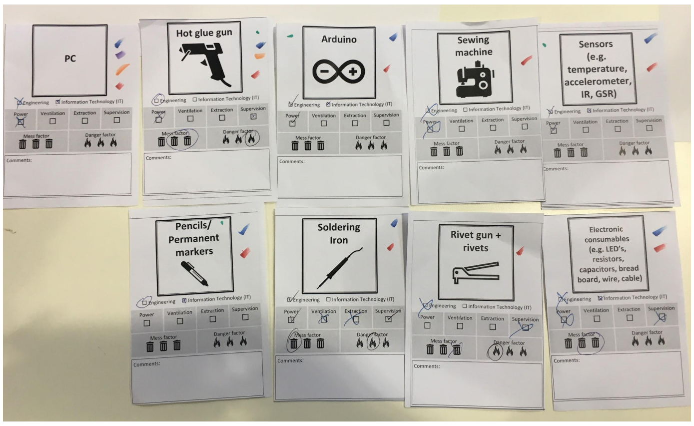

Figure 1: Card sort activity - wearable technology group

Sewing is for girls

Women have been marginalised in engineering for a long time, therefore anything seen as feminine is typically not considered the domain of engineers. Speaking of the first generations of women to join engineering programs in America, Bix (2014) writes:

In negotiating survival strategies, some female engineering students embraced a self-identity as "one of the guys," studying alongside men, often amid friendly teasing. Other women (or sometimes the same women at other times) deliberately displayed their femininity, proud of being interested in fashion, skilled in the kitchen, and enjoying hobbies such as sewing.

Today, 70 years later, women in engineering still speak of their experiences of being marginalised, and sewing is still considered women's work in many cultures. In Australia, as of May 2022, 87% of Sewing Machinists are female. 14% of Engineering Professionals are female (ABS, 2022) (only male/female sex listed - no gender data provided). Our students did not overtly reference gender as the reason, but many did not consider sewing to be as legitimate a manufacturing technique as, e.g. 3D printing.

Searle et al. (2016) examined the high/low dichotomy of craft and technology, finding that e-textiles can be an effective and gender-inclusive way of exposing young learners to technology. In an environment where so much effort is being made to attract women to study STEM, it is strange that sewing is still overlooked and underappreciated as an engineering technology. Given the prevailing gendered stereotypes for sewing and textiles, STEM fields might consider expanding their brand to be inclusive of sewing, and perhaps by extension, people who sew. Rather than seeking to dramatically shift the interests of prospective students who are women, trans or gender diverse towards traditionally masculine gendered technologies (cars, trucks, rockets, things that go fast etc.), would it not be easier and more inclusive to simply acknowledge textile design and fabrication as the engineering activity that it clearly is, and its practitioners as themselves engineers?

The COVID-19 pandemic - personal protective equipment (PPE)

Fairly early in the pandemic response, governments worldwide moved to recommend or mandate mask wearing. PPE was in short supply in Australia and contributed to many health care workers being infected with COVID- 19 (Ayton et al. 2022).

The response of the WHO to the COVID-19 pandemic in relation to PPE was to recommend the creation of 3-layer fabric masks styled after a surgical mask, given the ongoing shortage of higher protection N95/P2 mask stocks. We learned through industry contacts that there is an Australian standard for fabric masks. The challenge for the teaching team was to take something that was told to the public en masse, but make it more relevant to engineers.

The concept of masks was very familiar to the students, as they had become ubiquitous in our daily lives. We wanted to give the students agency, to use something they were so familiar with and break down the engineering involved in the design requirements of such PPE. For novice design students learning CAD for the first time, the challenge of fitting a range of human face sizes and shapes with a highly non-linear, deformable structure was considerable and frequently underestimated.

To give the students context to learn, we made sure the project could be designed and tested to the relevant Australian standard, AS/NZS 1716:2012 (2012), the key element being a fit and form test that used a bittering agent sprayed into a hood worn by the test subject. If the tester (one of our teaching staff) sensed a bitter taste, then the mask failed the test.

Unit Scope

The purpose of this unit in the degree program is to introduce generalist 2nd year engineering students to the specific mechanical engineering design methods, including engineering drawings and 3D modelling, project management, and decision making. The students prototype a solution using various fabrication techniques.

The mask project was designed to meet the unit learning outcomes, and the mapped Engineers Australia Stage 1 Competencies (Engineers Australia 2013) in engineering fundamentals, design, and application of engineering tools and techniques. This complex open-ended design project is appropriately scaffolded for a second year cohort through the provision of a detailed brief and plenty of hands-on skills development opportunities. Particularly, this unit aims to incorporate professional and teamwork competencies in the context of working as an engineering team performing an authentic design task responding to a brief. The assessment was worth 37% of the unit total, comprising 10% preliminary report, 12% final design report, 10% test and evaluation of the masks, and 5% evidence of professional team meetings.

Approach

Project approach

The brief given to students was a role play. We devised a client brief that told the students they had been approached by a filter manufacturer who, due to the pandemic, wanted to diversify their products and manufacture PPE using their P2 functionally tested filter fabric. To show the students as many different design techniques as possible, we asked for two types of masks, a predominantly textiles-based mask and a predominantly non-textiles based mask.

Teams were instructor selected and formed to be as heterogeneous with respect to the average WAM of the team members. We attempted not to leave any students of a particular gender isolated in a team, so typically there were always two or more women or gender diverse students in any teams with women or gender diverse members. CATME online peer evaluation was used to provide feedback on teamwork and moderate team marks for individual students.

The test requirements of the masks were proposed by teams and confirmed by the client. Intuitive filter changes, ease of donning/doffing and fit adjustment, and a Qualitative Fit Test using a sprayed bittering agent and test hood as per AS/NZS 1716-2012 (2012).

The teams produced a preliminary mask submission report, laying out their initial research, creative designs and recommendations. Each team member had to design a mask to meet the criteria and constraints the students had developed, and the teams had to choose one textile design and one non-textile design to manufacture. This was worth 12% of their overall grade. Once this report was completed, the staff compiled a 29 page report of the highlights of the class and their own functional analysis and discussed what teams missed, so all teams benefitted from everyone’s insight.

With the assistance of an industry sponsor, we were able to purchase 2 square meters of filter fabric that had been formally tested to AS/NZS 1716:2012 and passed the requirements for respirators in Australia. We supplied the on-campus teams with access to consumer-grade sewing machines, some basic prototyping fabric (cotton twill), and sewing kits. The students also had access to an overlocker and embroidery machine that could be utilised for special seams or decorative elements.

Approach to evaluation

To evaluate the project's success, the staff observed students in class and conducted detailed discussions with each team about how the project was progressing. The staff met weekly to discuss the project's progress and clarify required sections of the brief. At the end of the semester, the students were asked to complete Student Evaluation (SETU). Some of their thoughts are shown in Student Perceptions.

Outcomes

Student achievement

Most of the students used a sewing machine to fabricate a mask, and all who took the team task seriously did very well in the project. The students who were not successful in the unit were typically disengaged from their teams and did not participate to a satisfactory level with the team. Project mark distributions were the same compared to prior offerings of the unit.

Student perceptions

Overall, most students liked the project-based learning approach of the unit. Some students noted that the open-ended brief and the range of equipment and facilities at their disposal gave them a lot of freedom in their solutions.

- *The unit, as a whole, was one of the best I have taken yet. The project was a clear highlight and allowed me to extend myself beyond the restrictions present in other units.*
- *I also found the relative freedom of the specialised workspaces and design brief very helpful in terms of the project.*
- *It is very very different from other units in university where all you do is prepare for the final exam, overall, very hands on and practical, and useful!*

Other students struggled with the project's open-ended nature, which we find typical across the first design units in all engineering specialisations. A few students were critical of the choice of masks and sewing, as they had heard from previous cohorts of students that this unit was all about hard-core machining.

- *You have a class of 250 kids who want to be mechanical engineers and want to learn cool stuff and instead of doing mechanics and robotics people have to sew together shitty masks*
- *A return to more focus on the machining/manufacturing that was decreased this year. The new 3d printing and sewing was good, but it was unfortunate to lose some potentially really valuable content*
- *I liked 3D printing, sewing not so much*

Staff reflections

We were interested to note a general lack of fine motor skills within the cohort, perhaps due to the unfamiliar small scale of the sewing work for most students. Typically a few students from each team were delegated with the task of mastering the textiles processes, while others worked on CAD, the report or 3D printed components. The vast majority of our remote, internationally based students in the unit were able to sew their own versions of their team’s mask design. Many students appeared more comfortable with the newly introduced 3D printing technology rather than using the sewing machines. A small number of experienced sewists were identified in the class, all of them were women, and they all achieved strong project results for their teams and set a benchmark for the class. A small number of highly motivated (predominantly men) students worked very hard to develop their sewing skills and eventually achieved at the same level as the experienced sewists. Many students were surprised at the difficulty of sewing. Several reported newfound respect for the skills of their mothers and grandmothers, some of whom were actually called upon to advise upon the project work (much to their surprise and delight, we heard). Interestingly, staff investigated two cases of potential academic integrity, where we believe students tried to submit masks that had been purchased commercially. We used interviews to probe these students’ clear lack of understanding of the manufacturing steps and processes utilised in the creation of their submitted work, and after failing to reproduce these exceptional results under invigilated conditions, penalties were applied.

Examples of student work



Figure 2: Examples of student-designed and fabricated P2 masks with removable filter elements

Conclusions

Providing students with the opportunity to design, build and test their designs allows them to appreciate and experience the engineering principles they are learning fully. By temporarily pivoting to a textiles and sewing-based major project for our second year mechanical engineering students, we allowed our many students, stranded overseas and participating remotely, to partake more equitably in this process. Unsurprisingly, we received significant push-back from some students, many of whom lamented their lost opportunity to build robots and “make cool stuff”. We suspect that prevailing gendered stereotypes and prejudices will continue to inhibit the acceptance of sewing and textiles as engineering technologies even though their relevance in the engineering world is significant. We will continue to make these technologies and training available to students in the future in our Makerspaces. Pleasingly some of our student teams did discover the utility of these new skills and equipment and have continued to use them regularly to manufacture parachutes for their rockets and covers for the wheels of their race cars, amongst other cool things.

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