AN INTRODUCTORY REVERSE ENGINEERING PROJECT TO ENHANCE TEACHING STAFF AND STUDENT COMPETENCE

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ABSTRACT
This paper details the development and evolution of a reverse engineering project undertaken by all first-year engineering students at Nottingham Trent University (NTU). The paper elaborates on how the teaching and assessment methods used in the project can be utilised to enhance student as well as teaching staff competence. It is argued that technical staff play a vital role in supporting and delivering project-based learning and are likely to receive more student feedback outside of formal student surveys. Consequently, increased technician involvement in the development of the project is utilised in the hopes of better capturing student learning needs and ensuring students are given a good first introduction to using hand and measurement tools. Simultaneously, delivering such a project requires the staff to learn new tools and acquire relevant skills, thereby enhancing faculty competence. Instead of using multiple, smaller and discipline specific devices reported previously, a single and larger device is reverse engineered across all disciplines for the project at hand. Reverse engineering the same device across disciplines is proposed as a means to move away from engineering silos by unifying the tools used and the skills gained during the project. Furthermore, student feedback and technician perspectives are presented to paint a holistic picture of the delivery of the project from the standpoint of students, technicians and the academic. Finally, recommendations are put forth on how to further improve the delivery of such a project and increase technical staff involvement in an engineering curriculum.

KEYWORDS
Introduction to engineering, reverse engineering, engineering design, CAD, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 11

INTRODUCTION
Nottingham Trent University (NTU) established a new engineering department in 2017 with a modern approach to delivering engineering education. The approach acknowledges that it is essential to develop the general skills of future engineers along with specialised skills (Suzuki et al., 2022). The delivery of this curriculum is built upon 4 pillars:

1. **Tools:** Graduate engineers have suitable toolkit to tackle engineering challenges
2. **Skills:** Graduate engineers have necessary skills to effectively use engineering tools
3. **Creativity:** Graduate engineers have the desire to put forth creative ideas on which they use their skills
4. **Delivery:** Graduate engineers have had experience of taking their creative ideas from concept to production in a timely and organised manner

Engineers in the industry can often find themselves working with unchartered, open-ended, and complex problems (Jonassen et al., 2006; Zhu et al., 2019). Therefore, the engineering curriculum at NTU focuses on experiential learning – allowing students to work on several projects, to give them an experience of what real world engineering challenges might look like. This is the opposite of traditional, didactic learning (Gadola & Chindamo, 2019) and instructors involved in delivering this type of learning aim to facilitate student learning as opposed to acting as mere transmitters of information. There is an abundance of literature to support the efficacy of project-based learning in improving students' collaboration skills, communication, academic achievement and learning motivation (Chen & Yang, 2019; Hmelo-Silver, 2004; Ralph, 2016; Yadav et al., 2011).

It has been argued that the students' wellbeing and social competencies within a team takes precedence over academic achievement in the delivery of quality project work (Flarup & Wivel, 2018). Indeed, graduates with market-oriented skills, such as managing projects, comprehension of engineering economics, teamworking skills, and (or) competence using engineering tools are more desirable for employers (Yang, 2019). In the pursuit of producing high quality and employable graduate engineers, budding engineers need to be put in learning environments that allow them to learn a multitude of skills simultaneously. Previous research has shown that such a learning environment is achievable through the implementation of CDIO standards (Butt & Siegkas, 2021; Deweck et al., 2005; Mazini et al., 2018; Siegkas, 2020; Yang, 2019)

A recurring issue in engineering education is the reinforcement of disciplinary silos (Fitzpatrick et al., 2021; Hoople et al., 2018). The ever-changing landscape of modern technologies in the fourth industrial revolution has brought interdisciplinarity front and centre (Roy & Roy, 2021) and highlights the importance of producing engineers with diverse expertise rather than being discipline specific experts. Moreover, it is obvious that contemporary and future grand challenges are not limited to specific disciplines and require an interdisciplinary approach to create innovative solutions.

In creating a conducive learning environment, it is important for the instructors to make learning easier for the learners and to work with them towards knowledge construction (Mohedo & Bújez, 2014). From personal experience, to become change agents, instructors must be aware of the learning outcomes and have significant involvement in planning project-based activities. Several project-based modules at NTU employ the services of technicians, for setting up workspaces/ laboratories as well as demonstrations. In essence, the technicians play a role in the delivery of these projects as instructors. This paper builds upon the work previously presented (Butt & Siegkas, 2021; Siegkas, 2020) and explores CDIO implementation in a first-year engineering project with a focus on involving engineering technicians in the planning and delivery of the project. This early involvement is strategic, in that the technicians are allowed to disseminate their technical knowledge to engineering students early on in their student journey and in doing so, the competency of the entire technical team is improved. An effort is made within the project to minimise the reinforcement of disciplinary silos, both within the student body and the technical team.

PROJECT DESCRIPTION

The reverse engineering project presented here is part of a core module (Innovation and Engineering Solutions) undertaken by all year 1 engineering students at Nottingham Trent University. The courses enrolled in the module are Mechanical, Sport, Biomedical and Electrical & Electronics Engineering. The module runs throughout the academic year and has 4 items of assessment, each contributing 25% to the module. The reverse engineering project is the first of many projects undertaken by engineering students at NTU; readers interested in previous iterations of this project are redirected to (Butt & Siegkas, 2021) and (Siegkas, 2020).

The project learning outcomes included:

- Recall engineering principles related to the properties of materials and engineering components to describe their interaction with the environment and end user.

- Describe characteristics of materials, components and devices and their applications
- Recognise the limitations in an engineering system by considering a product's materials, design, and assembly.
- Competently and safely use machinery, hardware and software in the design, assembly/disassembly, and production of components and/or products.
- Work as a member of a team to undertake a small engineering project and deliver its results in a format suitable for a relevant industrial audience or stakeholder.

Project delivery: There were 255 students enrolled in the module. Groups consisting of an average of 9 members were created, giving a total of 28 groups. The aim of the group project was to introduce first year students to reverse engineering by deconstructing an engineered device into its constituents, documenting these in a bill of materials and then examining these in detail by discussing the function of each constituent element and proposing how this can be improved before finally reconstructing the device. The groups had to design the deconstructed parts using Computer Aided Design (CAD) on Autodesk Fusion 360 (Autodesk, 2022) and then create a virtual assembly of these components. The reverse engineering workshops were structured as Gateways which were used as opportunities to provide feedback (CDIO Standards 1, 2, 3, 4, 5, 7, 8)

To enhance the CAD modelling skills of the students undertaking the project, CAD tutorials were run in tandem with the project. The project took place over 10 weeks, where 5 weeks were dedicated to workshop sessions where the engine was reverse engineered while the other 5 weeks were dedicated to CAD sessions. An outline of these sessions has been presented in Table 1. The sessions were run in an alternating manner, whereby students would attend one CAD session and attend the reverse engineering workshops in the following week.

Table 1: Outline of the reverse engineering project sessions

Reverse Engineering Project	
Session	**Content**
Workshop 1	Gateway 1: Preliminary analysis and Deconstruction
Workshop 2	Gateway 2: Deconstruction, Measurements and Documentation
Workshop 3	Gateway 3: Bill of materials
Workshop 4	Gateway 4: Functional analysis and proposed improvements
Workshop 5	Gateway 5: Reconstruction
CAD session 1	Introduction to CAD, Sketching, Extrudes
CAD session 2	Patterns, Revolves and Fillets
CAD session 3	Sweep and Loft (with guided lofts)
CAD session 4	Assembly and Animations
CAD session 5	Drawings and BoM

Separate workspaces were provided to students to work on the project. For modelling, students used the purpose-built design and simulation suite with high spec desktop computers where they could use the CAD software to learn and model their parts while the reverse engineering took place in the engineering design suite where hand/measurement tools were provided along with the engine and manual/guides (CDIO Standard 6). The engineering design suite is an open plan room with ample space for students to work in groups and has limited computers and a separate provision of laptops should they require these for documentation/ modelling. In the last three years, the reverse engineering project has evolved from using household appliances to discipline specific appliances and now finally standardising the reverse engineered device to an engine. The engine used for the project is provided in Figure 1.

Figure 1: Honda GP 160 Engine used for the reverse engineering project (Image courtesy of Honda)

Engine selection: The technical team were tasked to procure a suitable engine for a project of this scale. There were some challenges in the selection of the engine; some engines available on the market had very few parts and as such lacked the complexity needed to target the expected learning outcomes. It was crucial to ensure enough parts were available for all students to take part in the deconstruction, measure the parts, design them using CAD, create a bill of materials before finally conducting a functional analysis to suggest improvements. One of the engines that was explored was a small 49cc quadbike engine made by iMars (ebay, 2022) - the engine retails at £50. This engine was relatively cheap and had ample number of parts that were suitable for this project. However, the lack of standard part sizes for this engine meant finding the tools to deconstruct this engine would prove tricky. In essence, a significant number of tools would have to be procured to deconstruct this engine. After much deliberation, the technical team concluded that the budget had to be increased to procure a high-quality engine that was of an appropriate size, had ample parts and had standard sized parts. After exploring various options, Honda GP160 (Honda, 2022) was agreed upon as the most suitable option. These engines had the right number of parts, were small enough to transport easily and had metric sizing with every nut and bolt being an M6 x 10/12mm. The standard metric sizing meant that the tools were much easier to buy and in the event of loss/damage, spare parts were readily available. Only one engine was ordered initially for testing and once the technical team were satisfied with the engine build and ease of deconstruction, a further 29 engines were ordered for a total of £6,061.

Engine preparation: Upon delivery it was found that each engine had 25ml of oil to prevent the parts from seizing or sticking to each other under varying temperatures during delivery. The oil was first drained from the engine after which they were disassembled. The entire technical team (10 technicians) and the module leader were involved in the deconstruction of the engines to ensure everyone involved had an appreciation of the constituent parts of the engine as well as gain insights into how the engine functioned. Although 2 – 4 technicians were committed in the delivery of the project, all technicians had to undertake the deconstruction in case a cover was required in the absence of the primary technicians involved. Upon deconstruction, the engines were cleaned with WD40 and then put back together. It is noteworthy that the technicians involved in the deconstruction/ reconstruction had varying technical specialities; some had Biomedical Engineering technical expertise while some came from an Electronics background. Technicians were encouraged to learn how to use hand tools during this exercise to improve their competence and ensure they had ample knowledge to teach students the use of specific tools such as strap wrenches and bearing pullers.

Manuals and guides: A deconstruction manual was prepared while the technical team deconstructed the engines. Notes and pictures were taken at various stages of the deconstruction and a brief description along with some labels were later added to each picture to create a step-by-step guide. Once a first draft of the guide was created, another technician followed this deconstruction manual to deconstruct another engine. This exercise allowed receiving feedback on the first draft to ensure appropriate revisions were made. This process was repeated several times to perfect the deconstruction manual. The order of the document was also changed a few times to ensure the most optimum deconstruction methods were articulated in the deconstruction manual. The instructions had to be clear and easy to understand; they were created with the assumption that the students following this guide may have never seen an engine before. A similar approach was adopted in creating a reconstruction manual. It is noteworthy that the reconstruction steps were not simply the deconstruction backwards as some parts needed to be put back first before the other parts to allow easier access. In addition to the deconstruction and reconstruction manual, a Reverse Engineering Laboratory Manual was also prepared that the students could use to aid them in collectively document the reverse engineering project progress. This manual was split into 5 sections, each section corresponding to the gateways described earlier.

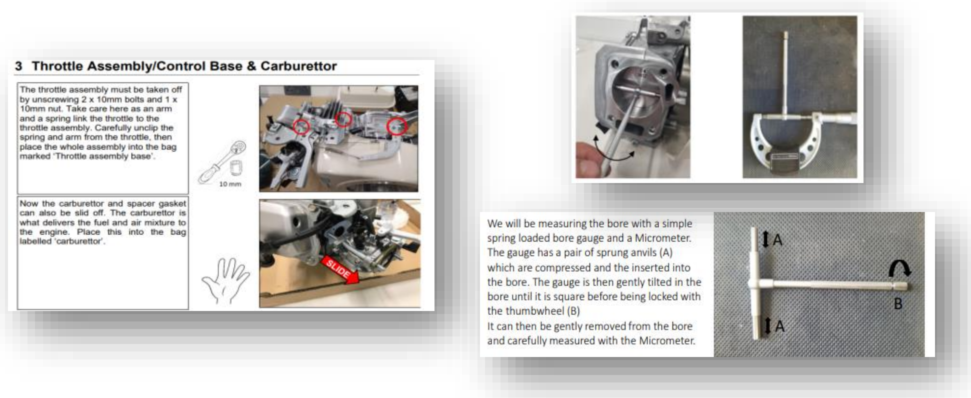

Figure 2: (Left) An extract from the deconstruction manual (Right) An extract from the measurement guide.

A measurement guide was also prepared and made available for the students to instruct them on the correct usage of specialist measurement tools. The measurement tools covered in the guide included a micrometre, spring loaded bore gauge and feeler gauges. Excerpts from the deconstruction manual and the Measurement Guide can be seen in Figure 2

Project gateways: Students were expected to fill in the reverse engineering laboratory manual on a bi-weekly basis. Each gateway of the manual focused on a specific task. At the start of the session, students were briefed on the task at hand and provided some pointers on best practices for successful completion of the task. Throughout the reverse engineering sessions, the module leader and a few members of the technical team were always present to supervise the students and facilitate them. Facilitation took the form of suggestions, demonstrations on how to use measurement/hand tools, assistance in designing components, and formative feedback at the end of the session. The module leader and technicians would also spend some time with each group every session as a form of mentoring/coaching to check in on their team dynamics and suggest ways to mitigate any issues and (or) lack of engagement.
The description of each gateway and the respective task is provided as follows:

Gateway 1: Deconstruction and Preliminary Analysis - Students were expected to provide a preliminary analysis while deconstructing the engine. Safety briefing and tools required to deconstruct the engine were provided to the students. The preliminary analysis was provided by the groups based on a set of probes provided in the laboratory manual, such as *what is the device? How does the user interact with the device? Why is the device designed in this way? How does the device work? How would you improve this device?*

Gateway 2 - Deconstruction, Measurements and Photographed Documentation: Students were expected to document the deconstruction of the device by itemising the engine and photographing the constituent components. Students were expected to place each deconstructed component in a labelled bag. The students were reminded that they had to produce CAD models of the constituent components and were encouraged to measure the components. Various measuring tools were provided to achieve this, and the students were encouraged to document the measurements in the laboratory manual.

Gateway 3: Bill of materials - Students were expected to document the deconstruction of the device by identifying the materials, function, interaction, price, etc. of the constituent components. A generic bill of materials was provided to the students to populate in the laboratory manual.

Gateway 4: Functional analysis and proposed improvements - Students were expected to conduct a thorough functional analysis of each component of the device and propose any improvements. Students were provided spaces in the laboratory manual to include two paragraphs; the first paragraph detailing what the part is (function and interaction), the material used to make it and how it has been manufactured and the second paragraph to suggest ways to improve the component.

Gateway 5: Reconstruction - Students were expected to reassemble the entire engine and provide an image of the reconstructed engine in the laboratory manual. Students were encouraged to note down steps taken in reassembling the engine, the tools used, and any challenges faced while reassembling

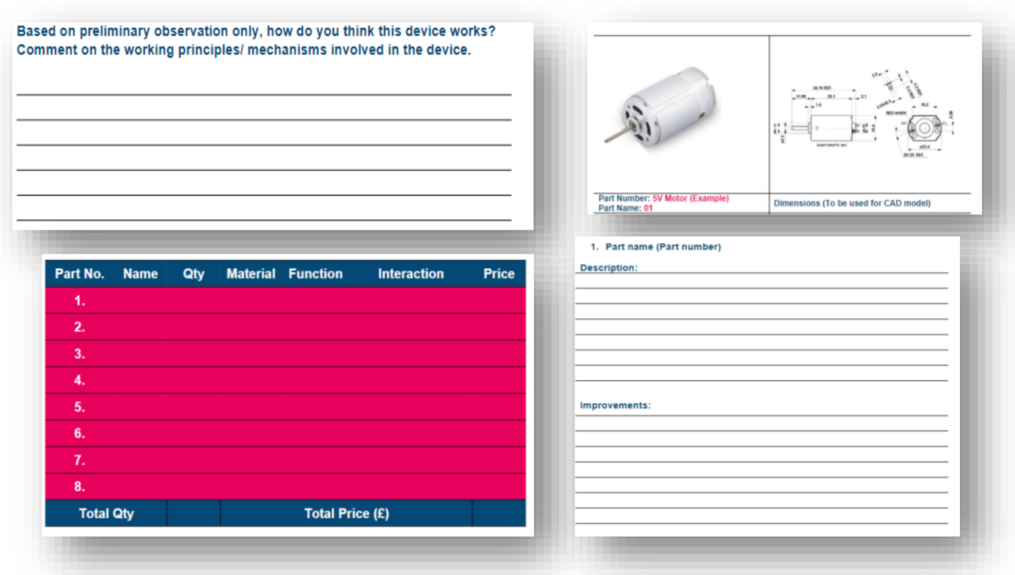

Figure 3: Some excerpts from various sections of the reverse engineering laboratory manual.

Project outcome: At the end of the project, students were required to submit a group report that detailed the following (CDIO Standard 11):

1. Background of the engine
2. Methods adopted and tools used
3. Bill of materials
4. Functional analysis of the engine components
5. Suggested improvements to the engine components

6. CAD models of the engine components and their assembly

Students were required to model at least 14 components using CAD. These components included air filter, fuel tank, exhaust, fan casing, recoil starter assembly, crankcase, crankcase cover, piston assembly, crank shaft, cylinder head and valves, camshaft, carburettor, fan, and flywheel. For details on the marking scheme, interested readers are redirected to (Butt & Siegkas, 2021)

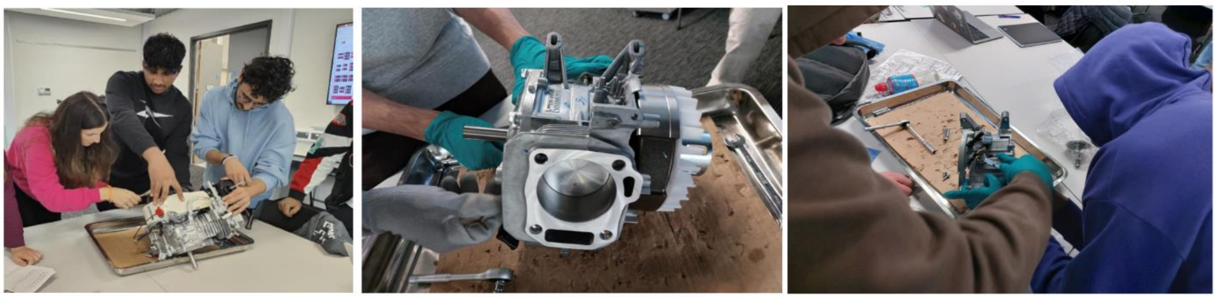

Figure 4: A few examples of the students at work in the laboratory sessions (Images courtesy of Group 16)

DISCUSSION

Module leader perspectives: The type of device used in the latest iteration of the reverse engineering project was selected for a few reasons. Standardising the device meant project management from an academic's point of view was easier. In each reverse engineering laboratory session, there was a quick CAD demonstration to contextualise modelling in terms of the engine being deconstructed. As an example, by the end of laboratory session 1, students had already learnt extruding in CAD in the week prior to this session. The demonstration focused on using extrude to create a component of the engine – the air filter in this example. Having run reverse engineering sessions with multiple devices in the previous iteration, it was hard to provide a similar demonstration as the devices were different for various groups. Standardising the device also meant that all students from various background worked on the same device following similar procedures using the same manuals and guides. Although engines are traditionally associated with Mechanical engineers; Electronic, Biomedical and Sport engineering students had an opportunity to work with a device that is traditionally not associated with their discipline. The aim was to give the students something to work with, without consideration for the relevance to their discipline, rather encouraging them work outside their comfort zone and focus on creativity, design skills, team working and project management. Standard devices also meant standard measurement and hand tools which worked well when considering resource management. All technicians, irrespective of their disciplinary backgrounds, deconstructed the same engine, ensuring they revisited their hand/ measurement tool skills if they were familiar with the tools already. If they had not used these tools before, this exercise encouraged them to learn tools and, in the process, enhance their competence (CDIO Standard 9).

Some reservations from Electronic, Sport and Biomedical engineering students on the type of device was expected based on prior experience. However, majority of the students engaged well with the device and found the sessions interesting, motivating them to learn more. In fact, the authors learnt quite a few new things such as the use of hand tools and the assembly of the engines used. As an example, author 1 learnt how to use a bearing puller, piston spring compressor and a strap wrench while author 2 picked up new CAD skills such as using 3D sketching and sweep to create gear teeth. The student outputs were impressive, in that the CAD modelling skills improved immensely over the course of the project than previous iterations of the project. This improvement is partly attributed to the complexity of the device used compared to previous iterations, but it is evident that the CAD demonstration in the laboratory sessions helped in making CAD modelling features such as extrudes and revolves more relatable. Some examples of the students recorded measurements and part modelling skills are shown in Figure 5, Figure 6.

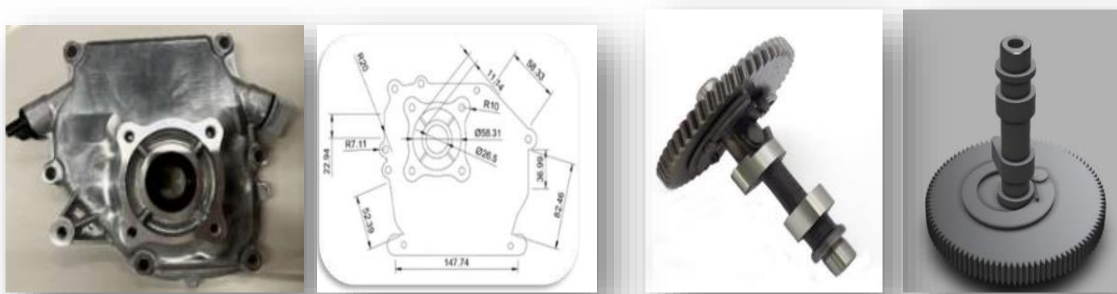

Figure 5: (Left) Measurements recorded in the laboratory manual (Right) CAD model of the engine camshaft (Images courtesy of Groups 20 & 26)

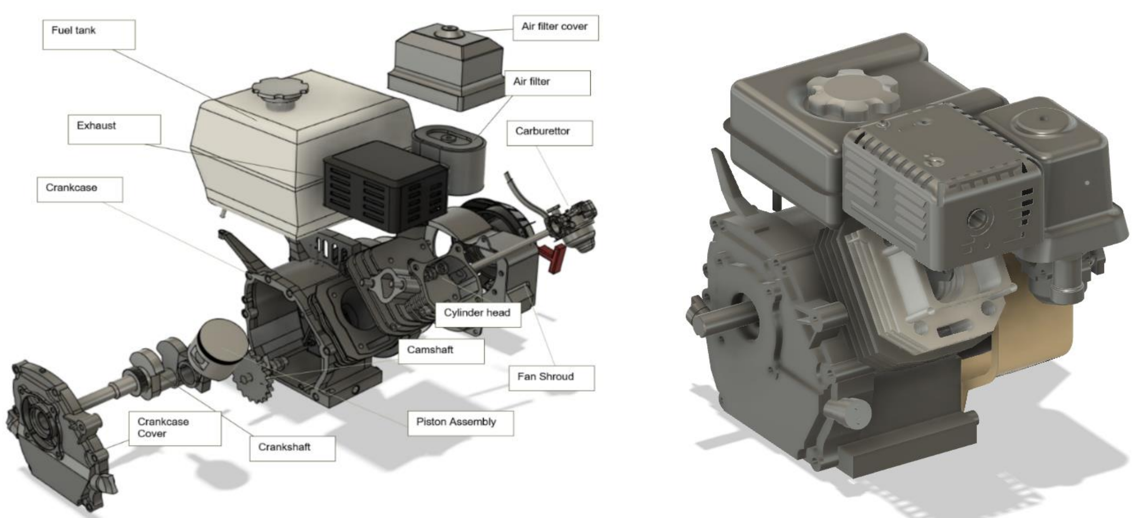

Figure 6: Examples of the CAD assemblies of the engine created by student groups (Images courtesy of Groups 7 & 9)

For the bill of materials, students were encouraged to focus on materials, manufacturing, and the pricing. Students were asked to justify how they arrived at the prices for each component. The prices were calculated in two ways: weighing the components, deducing its material based on research and the looking up standard material prices per unit mass from vendor websites or by simply looking up spare parts available online and then calculating the cost price of the part by subtracting an estimated profit margin from the selling price. An extract from a student group created bill of materials is presented in Figure 7.

Part no	Name	Quantity	Material	Function	Interaction	Price
1.	Air filter	1	Aluminum and Foam	Prevents or traps and holds any dust particle or debris from reaching the engine for better performance	Interacts with throttle valve Assembly	5.40 lsengineers.co.uk

Figure 7: Extract from a BoM created by a student group (Image courtesy of Group 20)

For the functional analysis and proposition of improvements, students were encouraged to research each part, its function, material, manufacturing methods as well as any alternatives that could be used for a specific part before proposing improvements. Students were reminded that when proposing improvements, they would need to discuss how the suggested improvements might have an impact on the components' prices, user-friendliness, and environmental impact (CDIO Optional Standard 1). In essence, students were asked to consider the Triple bottom line, catering to the social, economic, and environmental impact (or 3Ps – people, planet, and profit) and in doing so make trade-offs to conclude which suggested improvements from all the parts would they take on board in improving the entire engine. The aim was to improve the student's attention to detail while also ensuring they considered the broader context by considering modularity, ease of maintenance and use. Students made some fascinating suggestions, and most groups considered the bigger picture. As an example, a student group suggested improving the air filter casing by first deducing that air filters are injection moulded polypropylene and as such one improvement could be 3D printing these parts to avoid creating expensive moulds for injecting moulding and possibly reducing the size of the air filter. However, the group appreciated that a smaller size would impact the performance of the engine and due to Honda's mass production and economies of scale, neither of these improvements would have a measurable impact.

Working in groups, researching, deconstructing, documenting, communicating, designing, and interacting with the instructors allowed students to take part in active knowledge construction and aided in the development of their inter-personal skills (Tynjälä, 1999; Yang, 2019). The complexity of the device introduced this early in the student journey ensured students were not focused on their technical disciplines but rather the task at hand. It is noteworthy that the groups were discipline specific; this is largely due to timetabling conflicts. The authors feel that interdisciplinarity could be enhanced by creating mixed discipline groups, something that NTU students undergo later in their first and second years. As is normal with group working, some members contributed more to the group project in some groups and an attempt was made to mitigate this using peer assessments. A more robust assessment method is being deliberated on to ensure that all members of a group take part in all tasks of the project.

Technician perspectives: Hand tools used during the deconstruction of the engines were ratchets with 10, 12mm and 19mm sockets, 10mm spanners, 21mm spark plug sockets and a strap wrench. The use of tools was taught by technicians to each group so that groups had a more personal experience on how to safely use equipment around them. When reconstructing, the use of a piston ring compressor was also introduced. Demonstrations of the piston ring compressor was carried out by a technician and then the groups had the opportunity to use it if they wanted. It was observed that students from the mechanical engineering cohort were more familiar with the hand tools provided while biomedical engineering students needed more support. This is suggestive that the use of hand tools is more relatable for students who might have been enrolled in technical degrees such as BTECs. Students come into university with varying levels of talents and dispositions (Thomas & May, 2010). Introducing the engine in their first term of teaching ensures they develop key skills early on in their student journey, which can be used in various other modules as they go through the engineering curriculum. As an example, the NTU Engineering Grand Challenge is an annual event where students in year 1 and year 2 work as a group and apply their knowledge and skills to propose a creative solution to contemporary grand challenges. Learning how to work in a group and using different tools within the Reverse Engineering Project helps students come out of their comfort zone. Simultaneously, it ensures students understand how to use tools safely so that they observe safe working practices inside the laboratories and workshops. These skills carry through their entire student journey and are continually improved. Moreover, while working on the CAD model of the engines, student's modelling skills are improved which enables them to produce higher quality and more accurate models. Part of the CAD modelling within the Reverse Engineering Project involves producing technical drawings which allows technicians to better visualize what the students intend to manufacture and in turn makes manufacturing easier and more efficient. This clarity in communication between design and manufacture is an explicit expectation in an industrial setting.

By assisting on this project, the technical team gained an insight into the level of competency students come into university with. Much like the students, the skills of the technicians involved also varied. Technicians from a biomedical or sport engineering background needed extra support in using hand tools when originally deconstructing the engine in preparation for the module; this is partly because hand tools are not as regularly used in these disciplines as compared to mechanical and electrical engineering. During the preparation of this project, the technical team had to learn how to read and interpret official documentation for engines. As engines have not been used before, new hand tools and measurement tools had to be procured and all technicians were then trained in the use of micrometres, strain gauges and feeler gauges. The technician competency in the use of these tools was further improved by teaching the students on how to use them. The overall competency in the use of measurement tools improved when showing the students how to use the equipment. Technicians were also able to observe students using these tools and were able to appreciate the difficulties and challenges faced by the students. Technicians also observed what tools were used frequently and which components were prone to damage, enhancing the technical team's resource management skills.

Due to the nature of the project, technicians worked quite closely with the students in the practical sessions, allowing them to further accommodate the students. As an example, if a student was struggling with a specific tool, the technician could provide training instantly and the student applied this training right away, therefore reinforcing the learning undertaken. Another example is when the technicians observed that the provision of labelled bags for the engine components allowed students to better understand and compartmentalize engine components. This is an important observation as moving forward, technicians can repeat the same practice for other larger, project-based modules.

Student feedback: Technicians work closely with the students but are not always seen as instructors (Winberg, 2021) like academics can be, so students tend to give more honest feedback. Student feedback varied through this module; at the beginning students were apprehensive about starting such a big project but excited to try something new. As the module went on, they gained more understanding of why the project was given to them. As an example, initially some students from biomedical and electronic engineering became slightly frustrated that the task at hand was too complex and ‘irrelevant’ to their disciplines. By the end of the project, the same students were proud of what they had achieved and how much their CAD and critical skills had improved. One electrical engineering student commented to a technician “I would never have thought that 2 months from the start of the module, I’d be this good at CAD!”. In the past, students have rated this module quite highly and have given praise for how practical the module is. They felt there was always something to keep them busy during the 2-hour sessions and felt that it had prepared them more for the next term. More importantly, students felt the module had given them an insight into what industry might be like for them. The module received favourable responses in the end of year module evaluation survey. 89 students completed the evaluation and gave an average score of 4.7 out of 5 for “Overall satisfaction” with the module. However, there were some parts of the project that students didn’t like as much, such as the lack of research support around the bill of materials. Technicians supporting the module have taken this on board and have considered providing some links to the places they procure materials from so that students can see real life costings of material from vendor websites.

CONCLUSIONS

The methods and discussion presented here demonstrate how CDIO implementation led to meaningful learning for engineering students. The presented project’s learning outcomes and delivery methods ensured that the students were engaged in a way that the reinforcement of disciplinary silos was minimised, and the students gained a myriad of skills. The skills included (but are not limited to) teamworking, use of hand/measurement tools, efficient use of CAD, research, project management as well as documentation and professional reporting. Student outcomes presented here are a testament to the emphasis of environmental, social, and economic sustainability adoption through the entirety of the project. Involvement of the technicians early on in the development of the project delivery enriched the learning experience for the students and helped enhance the competence of the technicians and the module leader. Some examples of enhanced faculty competence include time and resource management. Increased technician involvement meant documentation for engine deconstruction was comprehensible for the students.

Based on delivery experience and student feedback, some suggestions for improvement include offering more support to the students in creating a bill of materials by providing a list/ website links of approved material suppliers. Technicians also aim to create video tutorials that demonstrate the use of hand and measurement tools to ensure students are given autonomy and do not rely on technicians for demonstrations. It is suggested that mixed discipline student groups should be formed to further minimise the reinforcement of disciplinary silos and a more robust method of assessment must be adopted to ensure all students engage equally with the project tasks.

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REFERENCES

Altringer, B., & Habbal, F. (2015). Embedding design thinking in a multidisciplinary engineering curriculum. *VentureWell. Proceedings of Open, the Annual Conference. National Collegiate Inventors & Innovators Alliance.*

Autodesk. (2022). *Autodesk Fusion 360*. https://www.autodesk.com/products/fusion-360/
Brodeur, D. R., & Crawley, E. F. (2005). Program Evaluation Aligned with the CDIO Standards. *Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition Copyright 2005, American Society for Engineering Education*.
Butt, A., & Siegkas, P. (2021). Integrated CAD and Reverse Engineering to Enhance Conception and Design. *Proceedings of the 17th International CDIO Conference, Hosted Online by Chulalongkorn University & Rajamangala University of Technology Thanyaburi, Bangkok, Thailand, June 21-23, 2021*.
Chen, C.-H., & Yang, Y.-C. (2019). Revisiting the effects of project-based learning on students' academic achievement: A meta-analysis investigating moderators. *Educational Research Review*, *26*, 71–81.
Deweck, O. L., Kim, Y., Graff, C., Nadir, W., & Bell, A. (2005). Engineering Design and Rapid Prototyping: A Rewarding CAD/CAE/CAM and CDIO Experience for Undergraduates. *Proceeding of the 1st Annual CDIO Conference Queen's University Kingston, Ontario, Canada June 7 to 8, 2005.*
ebay. (2022). *iMars® Motor 49cc Complete Pullstart Engine Quadbike ATV 2 Stroke Bike*.
Fitzpatrick, J. J., Byrne, E. P., & Fitzpatrick, J. J. (2021, June 14). *Non-discipline specific sustainability knowledge and competences in the Chemical Engineering Programme at UCC Non-Discipline Specific Sustainability Knowledge & Competences in the Chemical Engineering Programme at UCC*.
Flarup, J., & Wivel, H. (2018). Training the Staff-How to Develop Personal and Interpersonal Competencies at Faculty Level. *Proceedings of the 14th International CDIO Conference, Kanazawa Institute of Technology, Kanazawa, Japan, June 28 - July 2, 2018*.
Gadola, M., & Chindamo, D. (2019). Experiential learning in engineering education: The role of student design competitions and a case study. *International Journal of Mechanical Engineering Education*, *47*(1), 3–22.
Hmelo-Silver, C. E. (2004). Problem-Based Learning: What and How Do Students Learn? *Educational Psychology Review*, *16*(3), 235–266.
Honda. (2022). *Honda Engines - GP160*. https://www.honda-engines-eu.com/en/products/engines/gp160
Hoople, G. D., Mejia, J. A., Chen, D. A., & Lord, S. M. (2018). Reimagining Energy: Deconstructing Traditional Engineering Silos Using Culturally Sustaining Pedagogies. *2018 ASEE Annual Conference & Exposition, Salt Lake City, Utah*.
Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday Problem Solving in Engineering: Lessons for Engineering Educators. *Journal of Engineering Education*, *95*(2), 139–151.
Mazini, S. R., Leite, S., Aparecida Vieira De Moraes, P., Maria, M., Baptistella, T., & Ferreira Do Nascimento, R. (2018). The Integration of CDIO Standards in the Application of Project Based Learning as a Hands-On Methodology: An Interdisciplinary Case Study in Production Engineering. *Proceedings of the 14th International CDIO Conference, Kanazawa Institute of Technology, Kanazawa, Japan, June 28 – July 2, 2018.*
Mohedo, M. T. D., & Bújez, A. V. (2014). Project based Teaching as a Didactic Strategy for the Learning and Development of Basic Competences in Future Teachers. *Procedia - Social and Behavioral Sciences*, *141*, 232–236.
Ralph, R. (2016). Post-Secondary Project-Based Learning in Science, Technology, Engineering and Mathematics. *Journal of Technology and Science Education*, *6*.
Roy, M., & Roy, A. (2021). The Rise of Interdisciplinarity in Engineering Education in the Era of Industry 4.0: Implications for Management Practice. *IEEE Engineering Management Review*, *49*(3), 56–70.
Siegkas, P. (2020). Reverse Engineering and Introduction to Engineering Design. *Proceedings of the 16th International CDIO Conference, Hosted Online by Chalmers University of Technology, Gothenburg, Sweden, 9-11 June 2020*.

Suzuki, J., Kawasaki, K., Yajima, K., Chiba, S., Takeshima, H., & Kubota, Y. (2022). Visualizing the Effectiveness of Cross-Course-Typed PBL on Generic Skills. *Proceedings of the 18th International CDIO Conference, Hosted by Reykjavik University, Reykjavik Iceland, June 13-15, 2022*, 292–301.
Thomas, L., & May, H. (2010). Inclusive learning and teaching in higher education. *The Higher Education Academy*.
Tynjälä, P. (1999). Towards expert knowledge? A comparison between a constructivist and a traditional learning environment in the university. *International Journal of Educational Research*, *31*(5), 357–442.
Winberg, C. (2021). The Making of Engineering Technicians: Ontological Formation in Laboratory Practice. *Engineering Studies*, *13*(3), 226–248.
Yadav, A., Subedi, D., Lundeberg, M. A., & Bunting, C. F. (2011). Problem-based Learning: Influence on Students' Learning in an Electrical Engineering Course. *Journal of Engineering Education*, *100*(2), 253–280.
Yang, Y. (2019). CDIO Implemented Projects in a Computer Aided Design Course. *Proceedings of the 15th International CDIO Conference, Aarhus University, Aarhus, Denmark, June 25 – 27, 2019*.
Zhu, J., Liu, R., Liu, Q., Zheng, T., & Zhang, Z. (2019). Engineering Students' Epistemological Thinking in the Context of Project-Based Learning. *IEEE Transactions on Education*, *62*(3), 188–198.

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