INTEGRATED CAD AND REVERSE ENGINEERING TO ENHANCE CONCEPTION AND DESIGN

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ABSTRACT

This paper details the adoption of a methodology of integrating CAD with reverse engineering to enhance the conception and design skills of first year engineering students. The students are given an engineered device to reverse engineer via physical deconstruction and redesign via CAD as a group. The aim of administering this methodology is two-fold; firstly, to ensure students from various engineering backgrounds (Mechanical, Electronic, Biomedical and Sport Engineering) reverse engineer devices relevant to their discipline and specifically work on CAD models of these devices to enhance relatability. Secondly, to ensure students appreciate and adopt the underpinning practices involved in the design and conception of engineering devices. As opposed to dictating specifications, the redesign of the device is left at the discretion of the students to encourage a student-centred approach whereby the students take on an active role in the learning process. Additionally, designing and deconstructing the same device as part of a group ensures higher student engagement. This paper demonstrates the efficacy of the adopted approach by providing various examples of students' Reverse Engineering/ CAD outputs as well as assessment statistics. The paper also details the online support provided in addition to the on-site teaching to aid optimum learning in a blended learning environment.

KEYWORDS

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

INTRODUCTION AND BACKGROUND

Reverse engineering is an umbrella term for all the methods undertaken by designers and engineers to create a virtual approximation (parametric computer aided design model) of an existing product (Buonamici et al., 2018). This virtual model can then be reused, optimised, modified and analysed (Zhang, 2003). The process chain of reverse engineering can be broken down into: (i) measurement of correct dimensions (ii) processing measured data and (iii) creation of a computer aided design (CAD) model (Zhang et al., 1999). The industrial use of these techniques target reducing product development/ modification time and reducing production cost (Buonamici et al., 2018).

CAD modelling on its own has a variety of applications in industry and various University level courses, making it an integral part of any Engineering program (Paliokas, 2009, Asperl, 2005). It has been reported that teaching CAD in engineering courses ensures students improve three -dimensional (3D) thinking, solid modelling and creative ability (Heng-zhen et al., 2002). However, learning CAD is not easy for every student as in addition to requiring computer skills, the students need to have appropriate mental capacity, physical coordination and spatial vision (García et al., 2007). Moreover, student participation and motivation can pose a problem in CAD teaching (Paliokas, 2009). It is crucial to ensure students do not dislike the CAD modelling system or think it is complicated and must be offered enough variety of CAD education to ensure they enjoy acquiring these new skills (Kaminaga, Fukuda & Sato, 1995). As opposed to conventional lectures, some suggested methods such as combination of traditional lecture and video-tutorials as well as providing a variety of projects (Yang, 2019) have improved student motivation and learning experiences (Paliokas, 2009) and are flexible enough to cater to a broad range of learning styles (Lumsdaine & Ratchukool, 2003).

Past research has shown that CDIO standards implementation has enriched the learning experiences of undergraduate students (Deweck et al., 2005). CDIO provides context for beginning engineers to gain appropriate skills to take part in the development of engineering products and processes (CDIO Standard 1) (Brodeur & Crawley, 2005). Working in groups, for instance, encourages the development of inter-personal skills of the students and allows them to gain an integrated learning experience (CDIO standard 2) (Yang, 2019). Additionally, a provision of ample practical opportunities also encourages active learning (CDIO standard 8) (Shimizu et al., 2018). Problem solving and design exercises encourages engagement in engineering practice (CDIO standard 4) (Brodeur & Crawley, 2005). Provision of dedicated engineering workspaces supports and encourages social learning (CDIO standard 6) (Mazini et al., 2018). Moreover, designing curriculum with learning outcomes integrated in them and assessing these allows measuring the expected skills gained by the students (CDIO standard 11) (Brodeur & Crawley, 2005)

In view of the importance of CAD in reverse engineering and the wider engineering industry at large, this paper aims to demonstrate the amalgamation of CAD and reverse engineering at the very start of the students' engineering education journey at Nottingham Trent University (NTU). The module (ENGG10111: Innovation and Engineering solutions) reported here is a year-long module, however the teaching undertaken in the first term only is reported in this work. This paper builds upon the work previously presented (Siegkas, 2020) and the methods adopted have been inspired by similar reported modules (Zu et al., 2012, Deweck et al., 2005, Quist et al., 2017, Yang, 2019) that are in accordance with CDIO standards. Owing to the current pandemic (COVID 19), an aspect of blended learning is also reported here to demonstrate the new norm of Engineering education at NTU and its implementation within the CDIO context.

INTEGRATION OF CAD MODELLING AND REVERSE ENGINEERING

The class enrolled in this module had approximately 200, first-year undergraduate students from a variety of disciplines: Mechanical, Biomedical, Sport and Electronic Engineering. Integration of CAD with reverse engineering to first-year engineering students required significant deliberation and planning. The aim of the planning was not only to ensure a smooth learning experience in a blended environment but instead of focusing on a single engineering discipline, cater to all of them.

Keeping in view that this integration of CAD and reverse engineering had to take place over the course of a single term (8 sessions/ 4 months) and the students were new to CAD as well as reverse engineering, each of these components were planned separately. The dissemination and administration of these components is detailed here.

CAD modelling in a blended learning environment

For the first-year engineering students at NTU, Autodesk's Fusion 360 was taught as the primary CAD tool as has been previously shown (Siegkas, 2020). Owing to the current pandemic, a blended approach to teaching was adopted in which the students undertook 2-hour sessions each alternating week for 4 weeks on-site (in a dedicated design studio) while practice videos were provided to them using NTU NOW ("Nottingham Trent University Online Workspace (NOW)", 2021), the in-house virtual learning environment (VLE) used at NTU. The content covered for CAD is given in Table 1.

Table 1: Delivery of CAD on-site and online teaching

Week	Micro Drone Design with Fusion 360 (on-site)	Practice videos – author provision (Online)
1	Tutorials 1 - 6	Practice video 1
2	Tutorials 7-14	Practice video 2
3	Tutorials 15-24	Practice videos 3 & 4
4	Tutorials 25-27	Practice videos 5 & 6

The on-site sessions focused on a specific project, a provision of the Autodesk design academy and Airgineers as a recommended project to learn Autodesk's Fusion 360. The project – *Airgineers: Micro Drone Design with Fusion 360* (Figure 1) provides detailed tutorials in video as well as text format to conceptualize, design, assemble and test flight of a micro-class drone (Autodesk Design Academy, 2018). The areas of development the project provides are:

1. Understanding parametric CAD modelling
2. Familiarization with the Fusion 360 interface
3. Manipulating part materials and appearances
4. Using various CAD tools (fillets, chamfers, holes) to optimize design in terms of weight reduction with minimal impact on sustaining load.
5. Appreciating the differences in bodies, components as well as assemblies and demonstrating various techniques to move, align and assemble components.
6. Using simulations to test and optimize design.

The project was limited to conceptualizing, designing, assembling and virtual testing while manufacturing the designed components was not undertaken as the main aim of the administering the project was to introduce students to CAD and how it can be used for visual representation.

The tutorials were made available to the students via NTU NOW so they can practice in-class as well as at home. The sessions were supervised by an instructor to ensure students had access to professional support as and when needed.

In addition to the project, short practice videos were also provided on a weekly basis by the module leader. Based on the author's experience, CAD modelling engagement and motivations can be improved by simply ensuring the designed objects are relatable; not all the students necessarily take a liking to a certain project. The practice videos explored designing a variety of other objects to ensure most students could easily find something that interests them all the while getting enough practice on Fusion 360. The practice videos were short and demonstrated how various other creation tools such as revolves, lofts, sweeps, etc. can be used in Fusion 360. The content covered, designed components (Figure 2) and the CAD features demonstrated via the practice videos is given in Table 2.

Figure 1. Assembled 3D model of a Micro Drone (Autodesk Design Academy, 2018)

Table 2: Design creation and CAD features demonstrated via practice videos

Practice video	Design creation	CAD features demonstrated
1	Lego block	Extrudes, construction planes, rectangular patterns, fillet, mirror tool and shell tool
2	Simplified 4 cylinder in-line engine	Revolves, circular/rectangular patterns, assemblies
3	Hammer head	Lofts, guided curves/ rails, offset planes
4	Paper clip	Using canvas/images in CAD, geometry projection, sweep
5 & 6	Simplified variable pitch marine propeller	Fit-point splines, surface modelling, sketch projection, motion study, customizable drawings

Majority of the students appreciated the amount of content made available to them. Most of them preferred the practice videos over the project due to the various creation tools demonstrated in a short amount of time. As the content was released on a weekly basis for the project and the practice videos, most students were able to finish the project sessions and practice the videos in a timely manner and were given ample time in each on-site session to get support or additional help.

Table 3. Milestone or 'Gateways' covered in the reverse engineering project sessions

Session	Gateway
1	Deconstruction proposal
2	Deconstruction and photographed documentation
3	Bill of materials
4	Functional analysis and proposed improvements

Reverse Engineering project

Concurrently with the CAD modelling sessions, reverse engineering sessions which have been reported previously (Siegkas, 2020) were conducted on-site. The students were assigned a group within their discipline (Mechanical, Biomedical, Electronic or Sports Engineering). Each group had (on average) 5 members. The reverse engineering sessions were also conducted for 4 weeks. In this way, the students alternated between CAD modelling sessions and the reverse engineering sessions. Each week a briefing video was uploaded on NTU NOW detailing what the required outcomes of the weekly reverse engineering session are. The reverse engineering project was divided into 4 main 'gateways' which have been given in Table 3. The aim of the project was to allow students to observe a device relevant to their discipline and propose and conduct a deconstruction of the device (Figure 4) into its constituents. This allowed the students to see how the constituent components work together to achieve the desired purpose while also examining the materials and manufacturing processes used to produce the device. The insights gained via deconstruction allowed the students to propose improvements in terms of working principles, structure, materials, manufacturing, and sustainability.

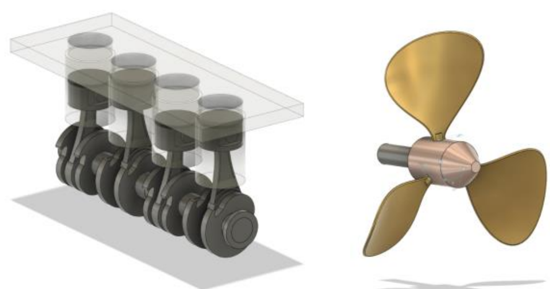

Figure 2. Selected design creations completed in the practice videos (Left) Simplified engine assembly (Right) Simplified marine propeller assembly.

For the reverse engineering sessions, each group was given a device relevant to their discipline. This was an update to the methods reported previously (Siegkas, 2020) and the changes were brought about with a focus on creating a blended learning environment. A laboratory manual was provided to all students to break down the project into milestones or 'gateways' to make it easier for the students to collect data and store it as a formal document. Standardization of the devices meant a deconstruction video for each device could be captured and uploaded on NTU NOW. This video could be viewed by students who were unable to attend the on-site sessions ensuring all students could view and analyse the deconstruction even if they were not physically present. The devices provided are detailed in Table 4.

Table 4. Devices provided to the various engineering disciplines

Discipline	**Device**
Mechanical Engineering	Mini air compressor
Biomedical Engineering	Digital blood pressure monitor
Electronic Engineering	USB speakers
Sport Engineering	Mini air compressor

Mini air compressors were the chosen device for the Mechanical and Sport engineering group (Figure 3). This simple device is used for sports balls, sports bicycles and even maintaining pressure in motorbike tyres and demonstrates the application of thermodynamics processes and air compression via reciprocating piston movement. It is a motor (or electromagnet) driven appliance that allowed engineering students to see electro-mechanical interface.

A digital blood pressure measurement device (Figure 3) was the chosen device for Biomedical Engineering. The motor driven device used an air pump and multiple air tubes to inflate the cuff for blood pressure measurement.

A USB speaker (Figure 3) was the chosen device for Electronic Engineering. The device works by sending electrical signals to a diaphragm which in turn converts the electrical energy to acoustic energy.

Figure 3. Devices provided to the students for the reverse engineering project (Left) Mini air compressor (Centre) Digital blood pressure monitor (Right) USB speakers. (Amazon, 2020)

Integration method and assessment

There was a single element of group assessment at the end of the term to assess the group's performance. The final submission was a formal group report on the reverse engineering project and had a weightage of 25% of the entire module. Part of this assessment was to produce a CAD model of the reverse engineered device. As the scope of this work is limited to the integration of CAD modelling with the reverse engineering project, readers are referred to the work presented previously by Siegkas (2020) for a more detailed breakdown of the remainder of the assessments for this module.

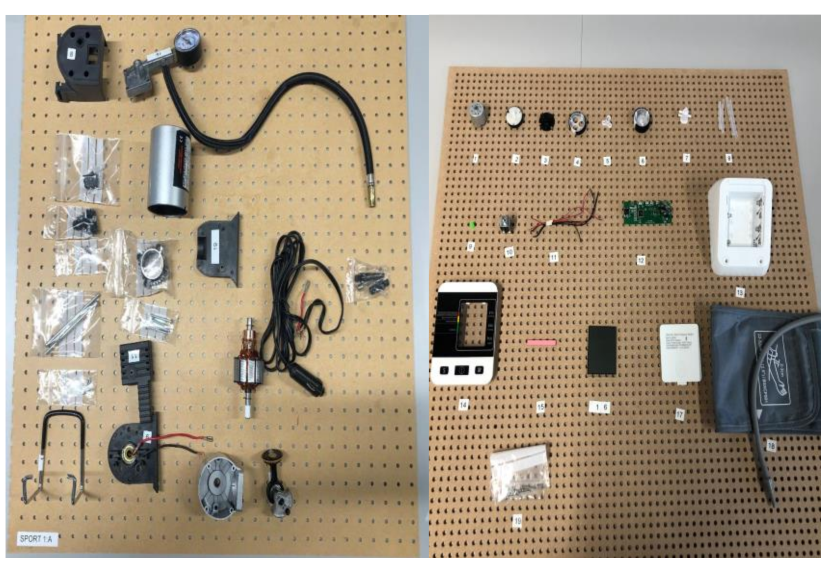

Figure 4. Examples of the deconstructed devices (Student provision).

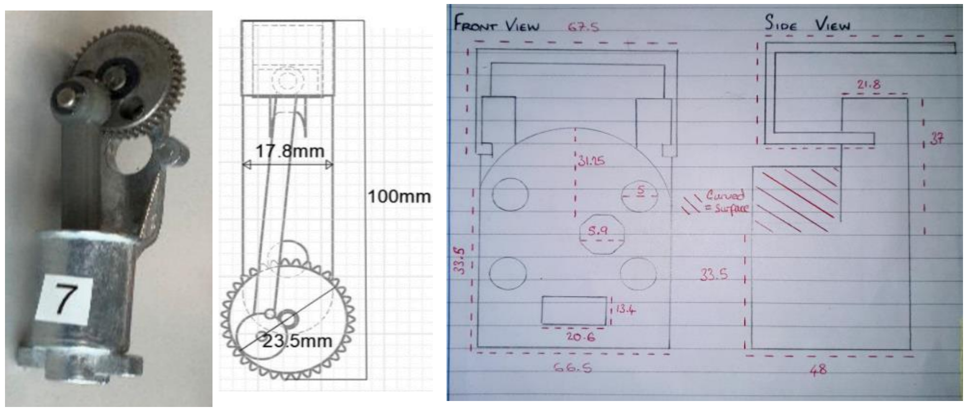

Figure 5. Examples of dimension measurement documentation in the lab manual (Student provision).

As the students started deconstructing their respective devices (Figure 4) in the second session (and had undertaken at least 1 CAD session), they were encouraged to start measuring the constituent components of the device, document this in the lab manual (Figure 5) and start designing a CAD model of each component. A separate section within the lab manual was provided to the students so they could document a photograph of each component along with a CAD model of the component. An example of the CAD model documentation has been presented in Figure 6.

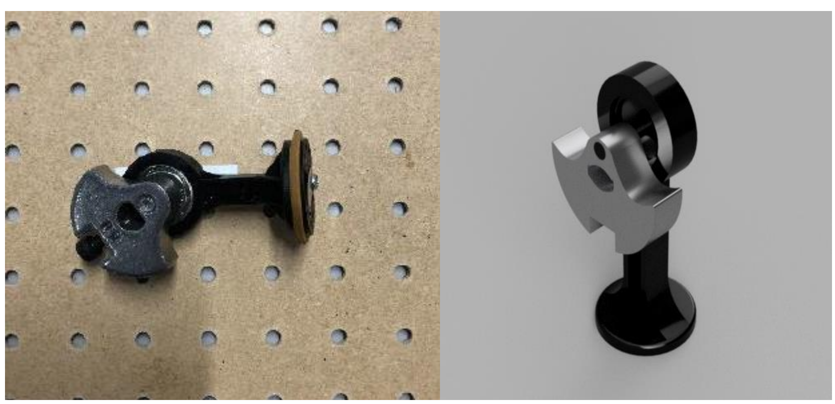

Figure 6. Example of CAD model documentation in the lab manual. (Left physical component (Right) CAD model (Student provision).

Marking criteria & statistics

Once all the reverse engineering and CAD sessions had concluded, the students were given time to compile a formal report on reverse engineering project. As mentioned earlier, CAD modelling formed a part of this report. Once the students had modelled all the components, they were required to assemble the components. Students were required to present their CAD models as general assembly drawings as well as renders of each modelled component and the final assembly. Marks were assigned for presentation of the model and ease with which the reader could understand the assembly of the components. The rest of the report was marked using a generic marking template. The grading criteria and the assigned weightages of each criterion have been presented in Table 5.

Table 5: Marking criteria for the reverse engineering project report

Criterion #	Marking criteria	Weightage (%)
1	General report structure	5
2	Figures and tables	5
3	Abstract	5
4	Introduction & Literature	10
5	Methodology	10
6	Deconstruction	10
7	Functional analysis and improvements	15
8	CAD model	15
9	Discussion	10
10	Conclusion	5
11	References	5
12	Peer assessment	5

The marking and assessment were carried out using online rubrics in NTU NOW, this was to ensure the students received timely feedback as a webpage and to avoid arithmetic errors in marking. Moreover, using online rubrics allowed documentation of marking statistics which are presented in the following sections. Standard NTU grading descriptors and award grades were used (*Grade based marking descriptors*, 2018).

A total of 38 reports were marked and the overall awarded grades and the percentages obtained for each criterion have been presented in Figures 7 & 8, respectively. It is worth noting that the peer assessment has been given full marks for the group report in this feedback as shown by criterion 12 in Figure 8. A separate peer assessment form was provided to the students to assess the performance of their peers and the final grade for each member was assigned via averaged peer assessment scores. Moreover, failing a marking criterion does not lead to failure in the assessment; a failed report must have an overall mark lesser than 40%.

The awarded grades and their implications are based on NTU's grading descriptors (*Grade based marking descriptors*, 2018) where 70% and above signifies a First-Class grade, 60% and above signifies an Upper Second class, 50% and above signifies a Lower Second class, 40% and above signifies a Third class while anything below 40 % is considered a fail.

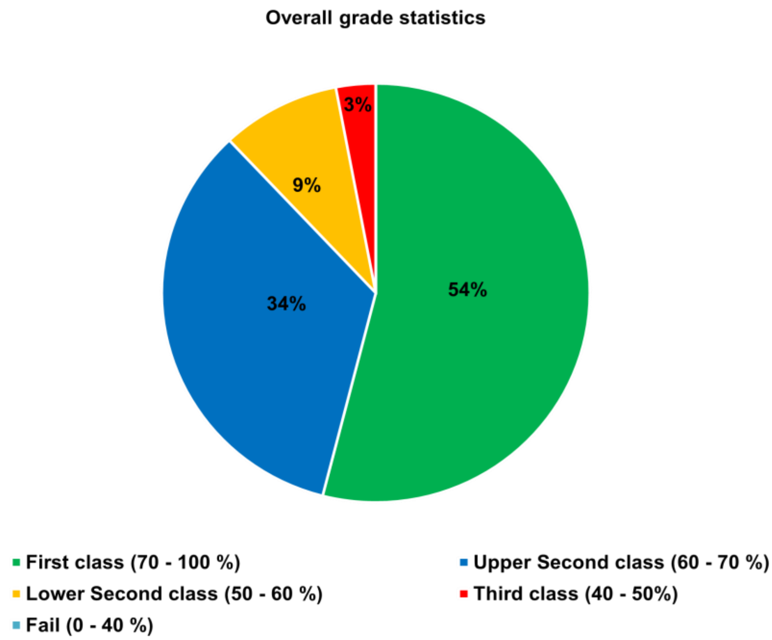

Figure 7. Breakdown of the awarded grades on the reverse engineering project report.

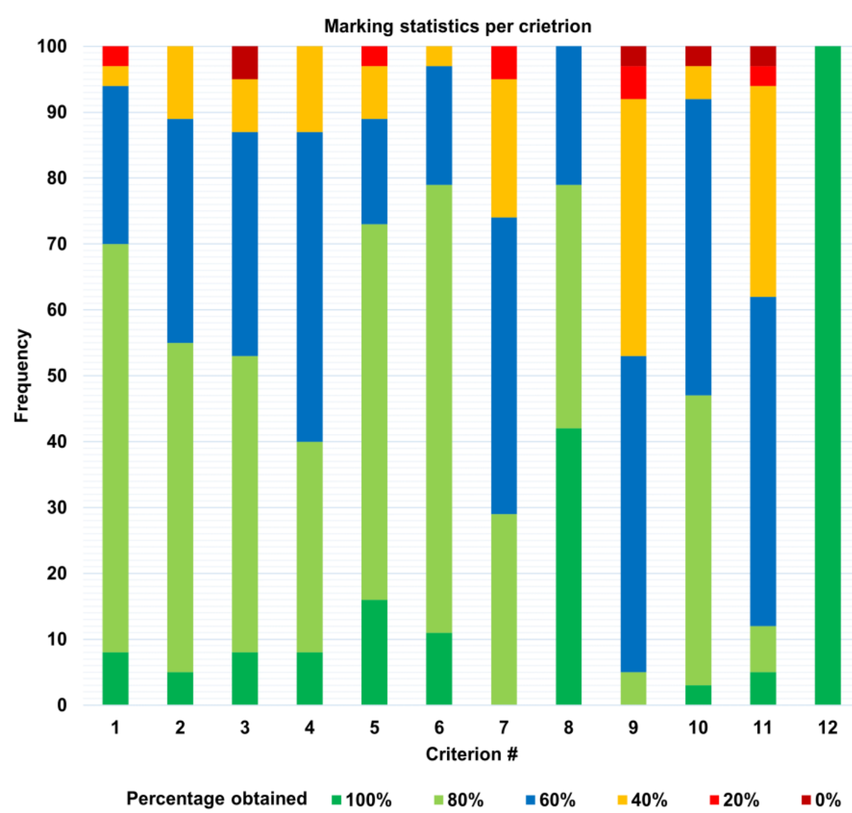

Figure 8. Breakdown of the percentage obtained for each making criterion.

DISCUSSION AND RECOMMENDATIONS

Deconstruction, measurements, research and documentation as a group allows students to appreciate engineering and design processes as well as the value of technical communication. As the students deconstruct and research each component of the device provided to them, they take part in the process of active knowledge construction (Tynjälä,1999). Being part of a larger team promotes social learning as well as the development of inter-personal skills (Yang, 2019). The successful projection of a physical model onto a virtual environment using CAD modelling demonstrates the need for the students to first gain appropriate CAD skills. A variety of practice videos and projects are provided however, these act as guides for various CAD tools as opposed to direct specification of how to create a CAD model of the deconstructed components. This encourages lifelong and active learning.

The delivery of the CAD and reverse engineering sessions in the current pandemic was a significant undertaking keeping in view that these students had never been exposed to reverse logistics or detailed CAD modelling. There were a few limitations in the way CAD was taught in a blended environment:

1. Not all students had access to Fusion 360 at home, on their personal computers. A virtual PC was provided by NTU to allow students to access PCs on campus, remotely and use Fusion 360.
2. The Micro drone design had been demonstrated using an older version of Fusion 360. Some students faced a few minor issues owing to the small differences in the user interface. The on-site sessions allowed these queries to be dealt with right away.

Similarly, given the current circumstances, it was not possible for all students to attend each on-site reverse engineering session. A Microsoft Teams stream was created for each group to ensure the groups could keep in touch and share any files or documentation conducted in the on-site sessions. The weekly online briefing videos ensured the students were up to date with what was taking place in the on-site sessions and the lab manual presented an excellent opportunity for the students for two reasons. Firstly, documentation of each gateway meant the students could easily share their work with each other even if some of the group members could not participate in the on-site sessions. Secondly, the structured documentation of the deconstruction, functional analysis, suggested improvements, CAD modelling and dimensioning ultimately made it much easier for the students to collate the information and compile a formal report. This claim is backed by the fact that none of the students failed the assessment and only 3% managed a Third class grade (Figure 7).

Investigating each criterion in detail (Figure 8) demonstrates that CAD learning was quite successful as it is the grading criterion with the greatest number of groups obtaining 80% or higher (criterion 8 in Figure 8). The student outputs were not only accurate in dimensions, but the photo-realistic renders provided by the students demonstrated an excellent design output when compared to the actual product provided to them (Figures 9, 10, 11).

Figure 9: Photorealistic renders of the designed speakers (left) assembled components (right) exploded assembly (Student provision)

As these are first year students, it must be noted that the grading statistics provide an excellent opportunity to improve certain areas of technical reporting. None of the student groups achieved a first class in the functional analysis and improvements sections nor in the discussions of their reports. It is important to observe that both these sections require the students to go out and actively seek information from quality engineering resources such as journal articles, books, materials and manufacturing database to provide details on function, improvements and back up their claims. A recurrent feature found in most reports was that some scientific claims or recommendations were based on opinion rather than scholarly work. This can be attributed to the student's research skills that are still building up, after all, this is their first term of engineering/ higher education. As this is anticipated, a short report writing online video (provision of the Nottingham Language center) was provided to the students. This does not necessarily help with research; however, it does help them see what is expected of them in a report. A suggestion here would be to run a workshop on research skills to ensure students can develop appropriate research skills at the very start of their respective courses.
During the on-site CAD sessions, it was observed that some students had a lack of relatability with the objects they were designing, such as the micro-drone or even some design creations of the practice videos. However, the integration of CAD with the reverse engineering project meant they would design something they can see, touch and measure. Some of the students would proactively gather their deconstructed items and bring them along to the CAD sessions to design with the components in front of them.

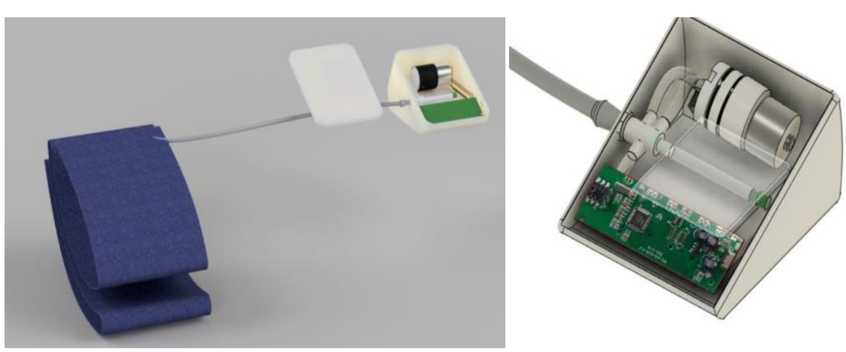

Figure 10. CAD model of the designed blood pressure monitor (Left) Photorealistic render (Student provision)

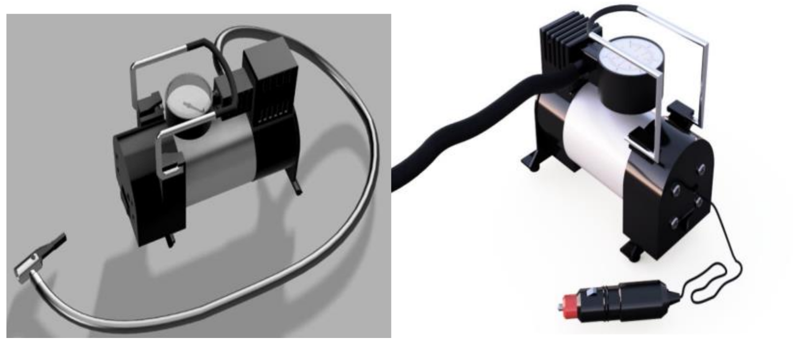

Figure 11. Photorealistic renders of the designed mini air compressor by 2 separate groups (Student provision)

Overall, the students were quite happy with how the projects were run and most of them enjoyed the integration of reverse engineering and CAD modelling. Student feedback seems to suggest that the independence allowed with CAD modelling encouraged creativity and the in-person supervised CAD modelling sessions had a very positive feedback. On one occasion, a student remarked “I enjoy the module especially working with CAD. I quite enjoy the space given by the lecturer, but they are always willing to sit down and explain something when I don't understand or need help.” The virtual development of the reverse engineered device also meant students could not only keep track of their progress but could see their efforts culminating into a finished product by the end of the term. This is backed by a comment made by a student “I like the practical aspect of this module and enjoy the fact I can actually physically see my progress at the end.” Providing the opportunity to students to design something they have deconstructed themselves ensured the student engagement was high throughout the sessions and resonated with a majority of the students, especially the ones who enjoy virtual prototyping as demonstrated by a student comment “I like the practical side of the course for example CAD as I like to physically create something on a digital environment then to make it in real life environment.” The only issue observed with the delivery of this project was the student’s issues with regards to online communication with their group members. The students cited “lack of time” and “lack of online availability” as the root cause. Communication is key for any group work; MS Teams streams were used to mitigate this. Given the number of students enrolled in the course and the high number of student groups, reaching out to check on each group seems counterproductive. Ultimately, with the hopes of the pandemic coming to an end and on-site teaching resuming on a regular basis, communication among the students will markedly improve. In the meantime, a suggestion here would be to breakdown the tasks for students before starting the project and asking each group to assign a member of the team to lead an individual task. As an example, one student in a group could look into the physical deconstruction, one could work on measurement and documentation and all of them could be encouraged to design individual components until finally assembling the model of the device. This will ensure there is a need to share information among the group but more importantly, assignment of tasks will allow students to take responsibility of their own contribution towards the overall group report.

As mentioned in a previous study (Siegkas, 2020), the assessment for the second term for this module is the design and manufacture of a wooden bridge as well as design, manufacture, and optimisation of a support pier. A reasonable proposition would be replacing the bridge and support pier with the redesign and manufacture of some of the components of the reverse engineered devices. The first-year engineering students at NTU have access to a range of manufacturing machines such as laser cutters, 3D printers, CNC as well as manual lathe and drilling machines. The assessment can be built around redesigning and optimising selected components of the reverse engineered device. The optimisation can be in terms of material use efficiency and reliability of the designed components using safety factors as an indicator. The students could start by simply redesigning the components that can be manufactured, followed by optimising the design via simulations on Autodesk's Fusion 360 before finally manufacturing the optimised components using the manufacturing methods available to them. Having observed the student's appreciation of independent learning, opportunity for creativity and the hands-on elements of the module; allowing students to manufacture components that were initially reverse engineered, designed on CAD and optimised using simulation provides an excellent opportunity for year 1 engineering students to go through entire design and manufacture process and works well within the CDIO framework.

CONCLUSIONS

Through the above results and methods, it has been shown that CDIO implementation even in the current atmosphere led to extremely meaningful engineering education. The students worked as a group and were given ample support in a blended learning environment in the form of briefing videos, CAD practice videos, laboratory manual and deconstruction videos. The assessment of skills (CDIO standard 11), the high marks achieved, and the design outputs are a testament of the skills the students gained. The curriculum design and dissemination of project information was done in accordance with CDIO standards 1, 2, 3, 4 and 8 as has been demonstrated via literature and discussion of results. The provision of dedicated design spaces and deconstruction workspaces was also in accordance with CDIO standard 6. The positive feedback of the teaching team involved as well as the observed high student engagement demonstrates an excellent introduction to engineering for the first-year students at NTU.

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REFERENCES

Airgineers: Micro Drone Design with Fusion 360. Autodesk Design Academy. (2018). Retrieved 5 January 2021, from https://academy.autodesk.com/curriculum/airgineers-micro-drone.

Amazon. (2020). *Dibiao Heavy Duty Tyre Inflator Portable Car Tyre Auto Tire Inflator Pump with Radiator Metal 12V Air Compressor 100PSI with Nozzle Adapters, Accessory for Caravan Trips (Black And Silver)* [Image]. Retrieved 5 January 2021, from https://www.amazon.co.uk/Dibiao-Inflator-Portable-Compressor-Accessory/dp/B08KZZ1HVC/ref=sr_1_128?dchild=1&keywords=heavy+duty+air+compressor&qid=1610908190&sr=8-128.

Amazon. (2020). *Blood Pressure Monitor, Home Use Digital Upper Arm Automatic Measure Blood Pressure and Heart Rate Pulse with Large Cuff,2 x 99 Memories (Battery Included)* [Image]. Retrieved 5 January 2021, from https://www.amazon.co.uk/Pressure-Monitor-Automatic-Memories-Included/dp/B07PJ2RMS7/ref=sr_1_20?dchild=1&keywords=blood+pressure+monitor&qid=1599565961&refinements=p_76%3A419158031&rnid=419157031&rps=1&sr=8-20.

Amazon. (2020). *Trust Almo 2.0 PC Speakers for Computer and Laptop, 10 W, USB Powered, Black* [Image]. Retrieved 5 January 2021, from https://www.amazon.co.uk/Trust-Speakers-Computer-Laptop-

Powered/dp/B07G4SVXTC/ref=sr_1_3?crid=2G0CF8X8MX4ZE&dchild=1&keywords=speaker+under+10+pounds&qid=1599565543&sprefix=speaker+under+%2Caps%2C138&sr=8-3.

Asperl, A. (2005). How to teach CAD. *Computer-Aided Design and Applications*, *2*(1-4), 459-468. Heng-zhen, H. Q. N. D., & Chang-de, G. F. C. (2002). Research of Teaching Reform in Mechanical Drawing Course for 3D CAD/CAM [J]. *Journal of Engineering Graphics*, *1*.

Autodesk Design Academy. (2018). *Assembled 3D model of a Micro-class drone* [Image]. Retrieved 8 January 2021, from https://academy.autodesk.com/curriculum/airgineers-micro-drone.

Brodeur, D., & Crawley, E. (2005). Program evaluation aligned with the CDIO standards. *Proceedings of the ASEE-2005*, *10*, 1-10.

Buonamici, F., Carfagni, M., Furferi, R., Governi, L., Lapini, A., & Volpe, Y. (2018). Reverse engineering of mechanical parts: A template-based approach. *Journal of computational design and engineering*, *5*(2), 145-159.

Deweck, O. L., Kim, I. Y., Graff, C., Nadir, W., & Bell, A. (2005, June). Engineering design and rapid prototyping: a rewarding CAD/CAE/CAM and CDIO experience for undergraduates. In *Proceedings of the 1st Annual CDIO Conference, Kingston, Ontario, Canada*.

García, R. R., Quirós, J. S., Santos, R. G., & Peñín, P. I. Á. (2007). Teaching CAD at the university: Specifically written or commercial software?. *Computers & Education*, *49*(3), 763-780.

Paliokas, I. (2009). Reinforcing metacognition in CAD education using videotutorials. *Computer-Aided Design and Applications*, *6*(5), 613-623.

Kaminaga, K., Fukuda, Y., & Sato, T. (1995, January). Successful examples in CAD/CAE teaching. In *International Conference on Computer Applications in Production and Engineering* (pp. 214-221). Springer, Boston, MA.

Lumsdaine, A., & Ratchukool, W. (2003). Multimedia tutorials for drawing shear force and bending moment diagrams. In *The Annual Conference of American Society for Engineering Education - ASEE, Nashville, TN, June 2003*

Mazini, S. R., Leite, S., & Aparecida Vieira de Moraes, P. (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. In *Proceedings of the 14th International CDIO Conference, Kanazawa Institute of Technology, Kanazawa, Japan, June 28 – July 2, 2018*. (pp. 160-170)

Nottingham Trent University. (2018). *Grade based marking descriptors* [Ebook] (pp. 2, 3). Retrieved 7 January 2021, from https://www4.ntu.ac.uk/adq/document_uploads/quality_handbook/148404.pdf.

Nottingham Trent University Online Workspace (NOW). Now.ntu.ac.uk. (2021). Retrieved 6 January 2021, from https://now.ntu.ac.uk/.

Quist, J., Bhadani, K., Bengtsson, M., Evertsson, M., Malmqvist, J., Enelund, M., & Hoffenson, S. (2017). CDIO based engineering design and optimization course. In *Proceedings of the 13th International CDIO Conference, Calgary, June 18-22, 2017.* (pp. 298-314).

Shimizu, Y., Thollar, S., Anada, Y., & Hayata, N. (2018). The Application of CDIO Standards to Clinical Engineering Education. In *Proceedings of the 14th International CDIO Conference, Kanazawa Institute of Technology, Kanazawa, Japan, June 28 – July 2, 2018.* (pp. 385-396)

Siegkas, P. (2020). Reverse Engineering and Introduction To Engineering. In *Proceedings of the 16th International CDIO Conference, hosted on-line by Chalmers University of Technology, Gothenburg, Sweden, 9-11 June 2020.* (pp. 11-23)

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.

Yang, Y. (2019, June). CDIO Implemented Projects in a Computer Aided Design Course. In *Proceedings of the 15th International CDIO Conference*. Aarhus University.

Zhang, Y., Fan, Y., & Chu, X. (1999). Principle and key technologies of reverse engineering. *Journal of Kunming University of Science and Technology*, *24*, 42-46.

Zhang, Y. (2003). Research into the engineering application of reverse engineering technology. *Journal of Materials Processing Technology*, *139*(1-3), 472-475.

Zu, H. Y., Tian, M., Song, Y. J., & Yan, Y. J. (2012). Exploration and Practice on Reverse Engineering Comprehensive Innovation Training Based on the CDIO Mold. *Value Engineering*, *2012*(27), 57.

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