CDIO IMPLEMENTED PROJECTS IN A COMPUTER AIDED DESIGN COURSE

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ABSTRACT

Instruction of a Computer Aided Design (CAD) Course usually involves topics from three major disciplines: geometric modelling, computer graphics and engineering design. The traditional lecture-based instruction focuses on the analytical and theoretical portions of these disciplines, which has helped the students build a strong knowledge base of these disciplines. However, it also leads to the fact that many students may still lack the experiences to handle real engineering problems even after taking this crucial course. This paper discusses how to adopt the CDIO-implemented projects to a third year CAD course and help students to achieve their learning goals. It also discusses how to use the outcome based assessment tools to evaluate the attributes of the learners, which include design and creativity, communication and collaboration, proficiency of using engineering tools, project management skills and self-learning capability. The study has found that stressing and implementing active learning experiences through these projects can significantly improve the learning outcomes.

KEYWORDS

Computer Aided Design, CDIO Standards: 2, 5, 6, 7, 8, 11.

INTRODUCTION

In the University of Ontario, Institute of Technology (UOIT), Computer Aided Design is an engineering core course offered to all students in the programs of mechanical engineering, automotive engineering and manufacturing engineering. The major contents covered by the course include the topics such as geometric/solid modelling (e.g. curves, surfaces and solids), computer graphics, finite element analysis, CAD and CAM integration, product lifecycle management, virtual engineering as well as design optimization.

The author has taught this course since 2011 and has noticed that the traditional lecture-based instruction methods have played important roles on improving the analytical and theoretical skills of the students, which are very helpful to the students if they plan to continue the graduate studies or conduct R&D work in the future. However, aside from these capabilities, the industries usually prefer the engineering students to have many market-oriented skills, such as communications skills, capabilities to use the engineering tools, collaboration and teamwork, knowledge of engineering economics and project management, self-learning capabilities etc.

Since 2012, the Canadian Engineering Accreditation Board (CEAB) has required all the Canadian Universities to implement their engineering programs so that students graduated from these programs will possess certain graduate attributes (e.g. knowledge base, problem analysis, design, investigation, and use of engineering tools etc.). At the same time, many educators have pointed out that a systematic reform of engineering education is necessary (Crawley et al., 2007), and CDIO based approaches are recommended for implementing the engineering education (Lynch et al. 2007). Many educators around the world have adopted CDIO standards to plan their curriculum (Hallenga-Brink et al., 2017) and prepare the assessment tools. (Lantada et al., 2017) Studies have shown that implementation of CDIO standards to the engineering design courses can effectively combine the design theory, lectures with various hands-on learning activities (e.g. sketching, CAD/CAE, fast prototyping), and provide much richer learning experiences to the undergraduate students. (deWeck et al., 2005) It has been found that to most engineering design courses, one of the critical issues about CDIO implementation is the skill evaluation system. (Munoz-Guijosa et al., 2016)

With more than five years' teaching experiences on the Computer Aided Design course, the author and his colleagues find that the sole dependence on the traditional lecture-based instruction method (illustrated in Figure 1) no longer works and the traditional evaluation tools such as paper-based exams can no longer accurately assess the students' performance. To achieve the teaching objectives, the instructor has specified the following course outcomes for a Computer Aided Design course: (CDIO standard 2)

1) Understand basics of geometric/solid modelling, computer graphics and feature modelling; e. g., represent curves and surfaces using parametric equations; understand the roles of a CAD/CAM/CAE system in the context of the product cycle; (CAD Knowledge)
2) Demonstrate the capability to analyze engineering problems with or without CAD/CAM/CAE tools; (Engineering Analysis)
3) Demonstrate the capability to conduct an investigation with given design specifications; (Investigation)
4) Demonstrate proficiency with product design and development processes; (Design)
5) Demonstrate proficiency with the application of CAD/CAE tools; (Use of CAD Tools)
6) Demonstrate strong communication skills to discuss, explain, present and promote engineering projects; (Communication Skills)
7) Demonstrate successful collaborations with peers and teammates; (Teamwork)
8) Demonstrate the capability to conduct simple project management and economic analysis, understand key issues in CAM and the data associativity benefits of CAD/CAM systems; (Economics and Project Management)
9) Have the capability to conduct self-learning for a commercial CAD/CAM/CAE system and to be a life-long learner. (Life Long Learning)

The terms shown in the brackets in the above are CEAB graduate attributes required in a Canadian engineering curriculum, and this paper will discuss how to use CDIO implemented projects to evaluate these attributes.

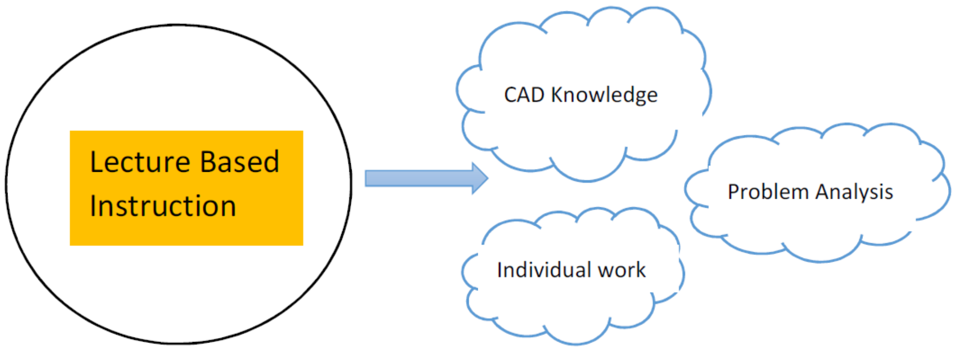

Figure 1: Traditional Instruction Method for CAD course

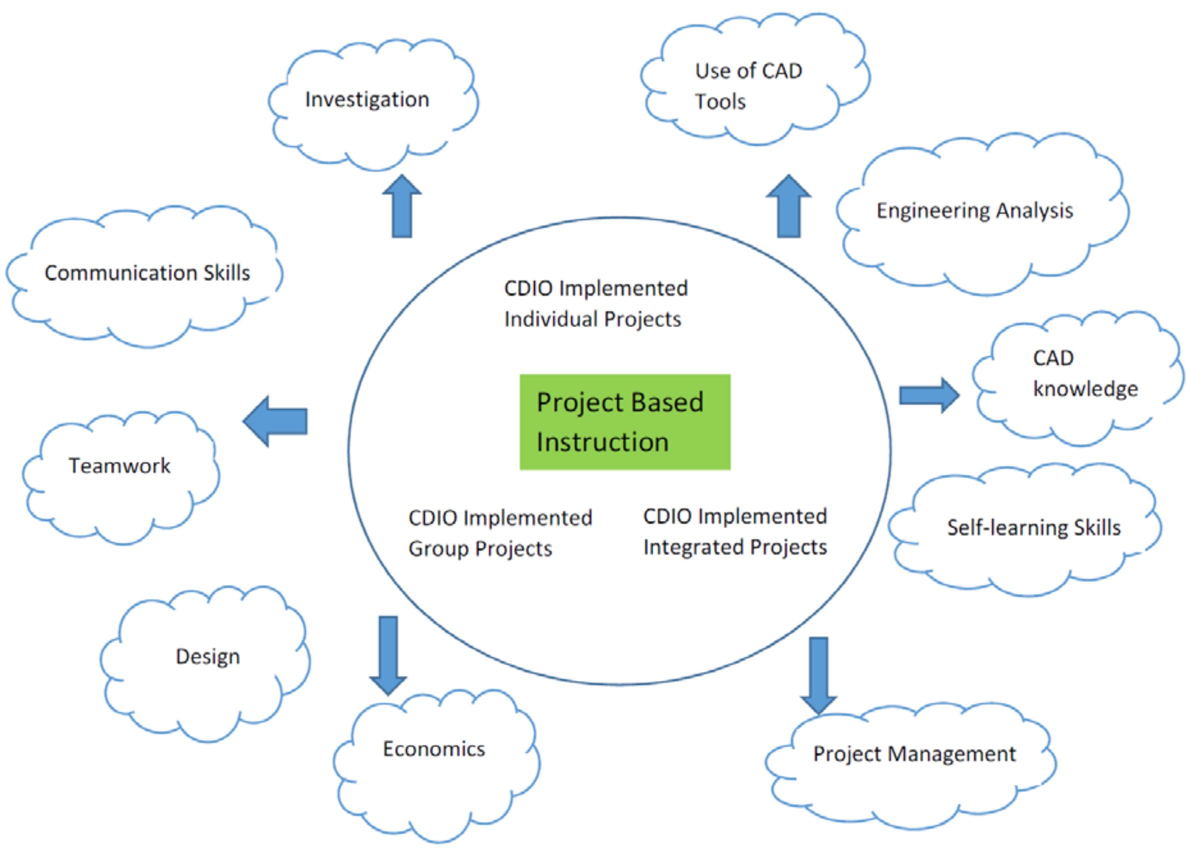

Figure 2: Project-Based Instruction Implemented with CDIO Standards

Since 2014, the instructor has initiated a Project based, CDIO implemented method to teach Computer Aided Design course. (Shown in Figure 2). The main feature of this teaching method is that aside from delivering the traditional lectures to the students, the instructor has developed three different types of projects that form the backbone of the course, and through them, the instructor expects the students will learn how to:

1. Design and develop products
2. Analyze and solve the engineering problems
3. Conduct technical investigations and market research
4. Manage the engineering projects
5. Collaborate with peers.

CDIO Implemented Projects

Table 1 shows the main characteristics of these different types of projects, which are all CDIO implemented.

Table 1 Comparison of Three Different CDIO Implemented Projects

Project Types	Group Size	Prototype Requirements?	Presentations Requirements?	Project Duration	Peer Review	CDIO standards
Individual Projects (Type I)	Individual	No	No	6 weeks	No	CDIO standard 2, 5, 8
Group Projects (Type II)	4-5 members per group	Yes	Yes	4 weeks	No	CDIO standard 2, 5, 6, 7, 8
Integrated Projects (Type III)	Up to 8 members per group	Yes	Yes	8 weeks	Yes	CDIO standard 2, 5, 6, 7, 8, 11

The individual project (type I project) is assigned right after the lectures, during which the instructor has introduced new theories or new concepts. (E.g. NURBS algorithm) It requires the students to follow the steps of Conceive, Design, Implement and Operate to develop a new product. It is an individual assignment, although it does not restrict the students from discussing with their peers. To complete this project, students must conduct some patent survey or literature research first and then generate the concepts with brainstorming. Students need to create technical sketches of the product and eventually complete a CAD model of it. To build the CAD model, students must teach themselves a new graphics software chosen by the instructor. (E.g. Rhinoceros) Finally, the students are required to write an essay to make comments about the CAD software and share their learning experiences accumulated through this project.

The instructor assigns different group projects (type II project) to the students as well. These projects have different storylines and the students call them “Case Studies”. Although these projects cover different engineering topics, the instructor designs them carefully to achieve the following goals:

1) All the projects must be completed in groups so that students can gain integrated learning experiences (CDIO standard 7). While doing these projects, students not only need to review and practice the topics that the instructors have delivered in the lectures but also need to collaborate with their classmates, which require interpersonal skills. In addition, all the groups must present their projects in front of the classes and it is mandatory for the rest of the class to ask them questions after presentations. Through these interactive activities, the instructor expects students to learn how to apply their knowledge to the engineering practices, how to address their concerns and how to respond to the doubts or criticism in a professional manner.

2) These group projects require students to go through an active learning process (CDIO standard 8). The instructor does not offer direct guidelines to the students. Instead, he will offer a list of technical resources (e.g. software, books, articles, equipment) that may be helpful to the students. Through group discussions and meetings, students make their own decisions about how to use these resources. Students usually explore these resources through self-learning and teamwork, but if necessary, the instructor or teaching assistants will provide some suggestions.

3) Through these projects, the instructor help students understand and solve real engineering problems. Although topics of these projects are different, students’ works still focus on the major aspects of the product development life cycle: market research, industrial design, engineering analysis and manufacturing. Students will gain design and build experiences (CDIO standard 5) through these projects.

4) Students can complete their projects through CDIO implemented workspace (CDIO standard 6). UOIT has regular CAD laboratories, which host more than 60 desktop terminals with more than 100 different software systems. In addition, every UOIT engineering student has a laptop assigned from the school, with the installation of all the required software systems. In 2017, the Engineering Faculty of UOIT opened a new Design Studio. This design facility has equipment that students can use with no costs (e.g. 3D scanner, 3D printers etc.) Two machine shops are also available for undergraduate engineering students.

The third type of projects is the integrated project (Type III). It is comprehensive and similar to an industrial project. It not only requires students to develop a product system but also requires them to conduct customer surveys, organize the meetings, create the budgets and execute a business model. Each project group could have a size of up to eight members. Based on their backgrounds and academic preferences, group members can assume their different roles in the team, such as project manager, industrial designer, engineering analyst or manufacturing specialist. This comprehensive project has specific requirements for collaboration and each member must fill the peer evaluation for their group work. The whole class will have the same project topic and it serves as a comprehensive tool to assess students’ performance. (CDIO standard 11). The grade of this project includes the students’ performance at four different areas: written project report, final presentation, prototype demonstration, and peer review. The instructor not only assess the students' achievements based on their paper-based submission and oral presentations, but also the physical prototype they build as well as feedback from their peers.

Assessment Rubrics

These CDIO implemented projects have offered a rich portfolio of assessment tools to evaluate the students' performance, which includes project reports, sketches, drawings, rendered pictures or images, CAD models, prototypes, oral presentations, review essays, peer evaluations etc.

Table 2 shows the detailed rubrics which the instructor has used to assess the nine major course outcomes: CAD knowledge, engineering analysis, investigation, design, use of CAD tools, teamwork, communication skills, economics and project management and self-learning skills.

The rubrics have followed the outcome-based CEAB accreditation criteria (Kishawy et.al, 2014) as well as the dossier of the Computer Aided Design course in UOIT (Yang, 2016). The rubrics specify four different levels of course outcomes, with the highest level as Level3 (students achieve a grade of 80% or higher) and the lowest level as level0 (students achieve a grade of 50% or lower). Level2 (students achieve a grade of 60% to 80%) suggests a student performance level which meets the expectations from the instructor. (Popiiev, 2015)

Some of the CEAB graduate attributes have been measured with only one or two types of projects. For example, for the CAD knowledge, only Type I project is used for assessment. This arrangement could give the instructor some flexibility while preparing the project topics.

The integrated project (Type III project) has been used for assessing most course outcomes and it has served as the most important assessment tools of the course (weight of 25% of the full course grade). Type I and II projects have their specific focuses due to their assignment sizes and project lengths while serving as an assessment tool. (E.g., type I project mainly serves for assessing the CAD knowledge, design and self-learning skills)

Results and Discussions

Figure 3 shows the results of the assessments from three classes (sections) opened in Fall 2018. There are 240 students in this course and they are from three different programs: mechanical engineering, automotive engineering and manufacturing engineering. They are divided into three separate lecture sections and students from different programs have been mixed within different sections. The instructor conducted three hours of lectures per week for each section, and there are two weekly CAD lab hours offered to the students as well.

For each course outcome, Figure 3 has shown the number of students corresponding to different performance levels. The author has found that for all the course outcomes, the majority of the students have met or exceeded the expectations, and for some course outcomes such as communications and teamwork, students perform extremely well.

However, for the course outcomes such as knowledge base and self-learning skills, there are up to 15% of students who either fail or marginally meet the expectations. The author has noticed that both of these two-course outcomes have been assessed only with type I project, which requires individual work.

Table 2: Assessment Rubrics for CDIO Implemented Course Outcomes

Outcomes	Level 0 0-50% *Fails to meet expectations*	Level 1 50-60% *Minimally meets expectations*	Level 2 60-80% *Adequately meets expectations*	Level 3 80-100% *Exceeds expectations*
CAD Knowledge (Assessed with Type I Project)	Poor competence in geometric modelling and computer graphics	Students demonstrate limited understanding of geometric modelling and computer graphics.	Students demonstrate the ability to apply the fundamental theories of geometric modelling and computer graphics to explain the schemes and algorithms commonly used in a CAD system.	Students demonstrate the ability to apply the theories of geometric modelling and computer graphics accurately to explain, modify and develop the schemes and algorithms used in a CAD system.
Engineering Analysis (Assessed with Type III project)	Inability to use appropriate knowledge and skills to identify, formulate, analyze, and solve complex engineering problems.	Students demonstrate limited ability to identify the type and primary objectives of the engineering problems, understand the methods used to solve the problems.	Students demonstrate the ability to decompose complex problems into relatively simple sub-problems and solve them with little errors.	Students demonstrate the ability to follow the scientific and engineering principle to analyze engineering problems and execute the solutions efficiently and accurately.
Investigation (Assessed with Type III projects)	Inability to conduct investigations of complex problems.	Students demonstrate limited ability to state an engineering problem or review of previous work.	Students demonstrate the ability to apply appropriate methods for data collection, select appropriate methods for implementation and use the results from previous work to draw a conclusion.	Students demonstrate the ability to analyze the results of previous work, summarize the limitations and implications and finally draw the conclusions and execute a successful plan for problem-solving.
Design (Assessed with Type I, II and III projects)	Inability to design solutions to the assigned open-ended problems.	Students demonstrate limited ability with product design and development process.	Students are proficient with product design and development process.	Students demonstrate impressive creativity and conduct product design and development proficiently

Use of CAD Tools (Assessed with Type I, II and III projects)	Inability to use common CAD tools to solve fundamental problems.	Students demonstrate limited capability to use common CAD tools to solve engineering problems, need external help while handling problems that require advanced skills.	Students demonstrate proficiency with the application of common CAD/CAE tools and could complete advanced problems with little external help.	Students demonstrate a high degree of proficiency with common CAD/CAE tools; become experts of one or two CAD tools.
Teamwork (Assessed with Type III projects)	Inability to work effectively as a member of a team.	Students demonstrate a limited appreciation of teamwork but still can work with another member fairly.	Students demonstrate the ability to contribute to a team, show the responsibility and help manage and organize the team.	Students demonstrate excellent collaborations with peers and show the leadership in a team
Communication Skills (Assessed with Type II and III projects)	Inability to deliver or describe complex engineering concepts. Inability to communicate with peers and colleagues.	Students demonstrate limited communication skills to discuss, explain, present and promote engineering projects;	Students demonstrate strong communication skills to discuss, explain, present and promote engineering projects;	Students demonstrate the ability to communicate with colleagues, and demonstrate the ability to present engineering concepts creatively
Economics and project management (Assessed with Type III projects)	Inability to apply the principles of economics and business practice, and inability to manage the engineering activities.	Students demonstrate limited ability to conduct basic engineering economics analysis and to manage engineering activities.	Students demonstrate the ability to conduct simple project management and economic analysis, understand key issues in CAM and the data associativity benefits of CAD/CAM systems.	Students demonstrate the ability to conduct moderate project management and economic analysis, understand key issues in CAM and the data associativity benefits of CAD/CAM systems.
Self-learning Skills (Assessed with Type I project)	Inability to conduct self-learning for a commercial CAD/CAM/CAE software.	Students demonstrate a limited ability to conduct self-learning for a commercial CAD/CAM/CAE system.	Students demonstrate the ability to conduct self-learning for a commercial CAD/CAM/CAE system and to be a life-long learner.	Students demonstrate the ability to develop a strategy to identify and address gaps in knowledge, undertake self-learning, and advance knowledge through research and other means.

Figure 3: Course Outcomes Assessed with CDIO Implemented Projects in UOIT (for all Fall 2018 semester)

The feedback from the students about these CDIO implemented projects are generally positive. Many students like the facts that the group projects (type II) and integrated projects (type III) allow them to learn actively. Compared with the traditional lecture-based instruction, these projects push them to learn through the collaboration and many students have improved themselves because they have been inspired and encouraged by their peers.

For the individual projects (type I), some students like it since it presses them to work independently. Many of them have pointed out that the challenges originated from this project actually have forced them to conduct active learning due to their desires to learn the software quickly and use it to solve the problems. However, there are also students who point out that they did not perform very well because of fact that this kind of project (type I) does not provide a platform where they can share their learning experiences; instead, they have been asked by the instructor to submit an essay describing their self-learning experiences.

The instructor has also collected the feedbacks from his teaching assistants and colleagues. The general agreement is that these projects have significantly enhanced the active learning experiences for the students. They also point out that one of the advantages of these CDIO implemented projects is that these projects can be used for assessing many course outcomes that traditional paper exams can't evaluate. However, these projects should not be used as only measurement tools for some course outcomes, such as knowledge base and use of CAD software. A combination with a traditional paper exam or an operational CAD lab exam could be a good solution.

LIMITATIONS AND CHALLENGES

Modifications and refinements are definitely required for these CDIO implemented projects, and the author identifies the following limitations and challenges:

The first challenge is about the accuracy of the assessment tools, especially for the group projects (Type II and Type III projects). Although each group assignment has been marked with cautions, and the mark of each team member has been adjusted through peer evaluation, there are still many factors that may lead to the errors. For example, the instructor has noticed some kind of mark inflation in the peer evaluations of group projects, and this can explain why course outcomes heavily affected by peer evaluations such as “communication skills” and “teamwork” have a much better performance compared with course outcomes such as “self-learning skills” and “knowledge base”. As pointed out earlier, “self-learning skills” and “knowledge base” are only assessed with individual assignment (Type I project), without being affected by the peer evaluations at all.

The other issue is about the workload of the instruction. The marking and assessment of these projects need more teaching assistants to help the instructor. In addition to the traditional marking works such as marking the project reports and lab reports, more works hours now are required for consultations, prototype demonstrations as well as evaluating the project presentations and discussions.

The third challenge is about the size of the class. The instructor noticed that the optimum class size is about 40 -60 students. If the class size is too large, it is hard for the instructor to control; while if the class size is too small, although the instructor may spend more time on each student, it will limit the flexibility for the instructor to select project topics.

In the future, more implementations are required to address the above issues. For example, the instructor considers using a double-blind peer evaluation process for the integrated course project. (E.g. invite students from parallel classes or previous classes to evaluate the group projects)

CONCLUSIONS

Through the above results and feedbacks, it can be concluded that the active learning (CDIO standard 8) has played a very important role in these CDIO implemented projects and has essential contributions to improve the performance of the students. These projects can push the students to learn through collaboration and self-learning. The data collected through these projects have shown that the students did very well in many courses outcome categories such as “Investigation”, “Design”, “Communications Skills”, “Teamwork” and “Economics and Project Management”. The author also believes that other CDIO standards, such as integrated learning (CDIO standard 7), design-build experience (CDIO standard 5) and CDIO implemented workspace (CDIO standard 6) have formed the foundation of these projects. The feedback from the students and colleagues regarding these projects are general positive. However, modifications and refinements for the implementation of these CDIO standards are crucial to achieve the continual improvements of this course.

REFERENCES

Crawley, E., Malmqvist, J. Ostlund, S. Brodeur, D. (2007). Rethinking Engineering Education. The CDIO Approach, 302, 60-62.

DeWeck, O., Kim, I., Graff, C., Nadir, W., Bell, A. (2005) Engineering Design and Rapid Prototyping: A Rewarding CAD/CAE/CAM and CDIO Experience For Undergraduates. 1st Annual CDIO Conference, Queen's University, Kingston, Ontario, Canada.

Hallenga-Brink, S., Sjoer, E. (2017). Design a Flexible, Choice-based, Integrated, Professionally Challenging, Multidisciplinary Curriculum. Proceedings of the 13th International CDIO Conference, University of Calgary, Calgary, Canada.

Kishawy, H., Sindu, T., Popiliev, R., Rosen, M., Zhang, D.,Mahoud, Q. (2014), Meeting the Outcome-based CEAB Accreditation Criteria: Engineering Programs at UOIT. Proceedings of The Canadian Engineering Education Association Conference University of Calgary. June 8-11, 2014, Calgary, Canada.

Lantada, A. D., Sevillano, J. (2017) Ten Years of CDIO Experiences Linked to Toy Design, Proceedings of the 13th International CDIO Conference, University of Calgary, Calgary, Canada. .

Lynch, R., Seery, N., Gordon, S. (2007) An Evaluation of CDIO Approach to Engineering Education, International Symposium for Engineering Education, ISEE-07, Dublin, Ireland.

Munoz-Guijosa, J., Lantada, A. D., Tanarro, E., Otero, J., Muñoz Sanz, J., Muñoz García, J. (2016) Engineering Design Course Transformation: From a Conceive-Design Towards a Complete CDIO Approach, Proceedings of the 12th International CDIO Conference, Turku University of Applied Sciences, Turku, Finland.

Popiliev, R. (2015) Exhibit 1 to CEAB Accreditation Visit for Manufacturing Engineering Program in UOIT, Oshawa, Ontario, Canada.

Yang, Y. (2016) Course Dossier for the Computer Aided Design course in UOIT. https://ecis.engineering.uoit.ca//Faculty-Engineering-and-Applied-Science/Department-Automotive-Mechanical-and-Manufacturing-Engineering/MECE-3030U/Fall-2017/dossier

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