THE CONCEIVE DESIGN IMPLEMENT OPERATE (CDIO) INITIATIVE – AN ENGINEERING PEDAGOGY APPLIED TO THE EDUCATION OF MARITIME ENGINEERS

Reference NO. IJME 1187, DOI: 10.5750/ijme.v164iA4.1187

J-B R G Souppez and **T W Awotwe** Mechanical, Biomedical and Design Engineering Department, School of Engineering and Technology, College of Engineering and Physical Sciences, Aston University, UK.

KEY DATES: Submitted: 18/04/22; Final acceptance: 31/01/23; Published: 27/03/23

SUMMARY

The Conceive Design Implement Operate (CDIO) initiative is an innovative engineering education framework aiming to produce industry-ready graduates. Over the past two decades, the approach has been increasingly popular, particularly in the mechanical engineering field, thanks to its practical approach and outcome-based assessments. However, the CDIO approach remains absent from the pedagogical tools employed in naval architecture curricula. This paper argues that, although unrecognized as such, modern yacht and ship courses have been employing an approach akin to that of the CDIO initiative. Four international case studies, in both undergraduate and postgraduate higher education, are employed to demonstrate that the courses under consideration indeed utilize the CDIO approach to engineering education. Furthermore, this paper identifies the CDIO initiative as a relevant pedagogy for the development of maritime engineers and naval architects, and provides applicable guidelines to implement CDIO. It is anticipated that this first recognition of the use of the CDIO initiative in naval architecture courses will contribute to formalizing the implementation of the CDIO initiative in this field, as well as enable greater synergies between the various disciplines of engineering education.

KEYWORDS

Conceive, Design, Implement, Operate, CDIO Initiative, Ship Design, Maritime Education, Engineering Education.

NOMENCLATURE

CDIO	Conceive Design Implement Operate
PBL	Problem-Based Learning
ROV	Remotely Operate Vehicle
RWL	Real-World Learning

1. INTRODUCTION

The Conceive, Design, Implement, Operate (CDIO) initiative was developed to equip engineers with a skillset better aligned with the expectation of employers, and rethink engineering education towards a more outcome-focused pedagogy. The practical approach of the CDIO initiative was refined over the past two decades (Brodeur and Crawley, 2005; Malmqvist, *et al.*, 2006; Crawley *et al.*, 2007; Crawley *et al.*, 2011; Crawley, *et al.*, 2014; Bennedsen, *et al.*, 2016; Malmqvist, *et al.*, 2017; Malmqvist, *et al.*, 2019; Malmqvist, *et al.*, 2020). It employs design-build-test projects to develop the fundamental knowledge and practical skills required for employment, which has proven to be particularly attractive in higher education. As a result, the CDIO initiative has had a significant impact on institutions worldwide, particularly in the mechanical engineering field (Crawley, *et al.*, 2011).

Much of the CDIO ambitions, namely, to prepare engineering graduates for employability through practical and experiential learning, are found in the yacht and ship design education literature (Barkley, 2012; Michaeli, *et al.*, 2015; Souppez, 2015; Vankov and Vankova, 2015; Souppez, 2018). Furthermore, there is evidence of practical design-build-test projects employed in naval architecture (Rigo, *et al.*, 2015; Anderlini, *et al.*, 2018; Dusek, *et al.*, 2018; Archer, *et al.*, 2021). However, the CDIO initiative remain unacknowledged in the education of naval architects. Yet, careful examination of published design-build-test case studies appears to suggest a CDIO-like pedagogical approach has been adopted.

Consequently, the aim of this paper is to demonstrate that the CDIO initiative has in fact been employed in in yacht and ship design, yet without being recognised as such. This will be supported by the review of four international case studies, at undergraduate (Anderlini, *et al.*, 2018; Dusek, *et al.*, 2018; Archer, *et al.*, 2021) and postgraduate (Rigo, *et al.*, 2015) level. Furthermore, this work endeavours to evidence the benefits of the CDIO initiative in naval architecture education, to support the development of novel and effective pedagogies.

The remainder of the paper is structured as follows. Section 2 details the background to the CDIO initiative, and address its parallel and difference with other established pedagogies, namely problem-based learning (PBL), and real-world learning (RWL). Section 3 chronologically reviews four international naval architecture case studies, at both undergraduate and postgraduate levels, against the CDIO's pedagogical characteristics. Eventually, Section 4 summarizes the main findings of the paper and the relevance of the CDIO initiative for the education of naval architects.

2. THE CDIO INITIATIVE

2.1 BACKGROUND

The framework of the CDIO initiative dates back to the late 1990s and originates from the Massachusetts Institute of Technology. The intention was to develop the next generation of engineers, with more practical skills to facilitate transition into industry. The CDIO standards were initially introduced by Brodeur and Crawley (2005), and further detailed by Malmqvist *et al.* (2006) and Crawley *et al.* (Crawley, *et al.*, 2007).

Since 2007, the standards have been updated twice. The CDIO standards 2.0 were adopted in 2014 (Crawley, *et al.*, 2014) and the rubrics have been further modified by Bennedsen *et al.* (2016), resulting in CDIO standards 2.1. These modifications have been relatively minor and have not changed the scope or the main contents of the standards.

An effort to update the CDIO standards from version 2.1 to 3.0 was initiated in 2017 (Malmqvist, *et al.*, 2017), identifying that as engineering education best practice and the context of engineering are continuously evolving, also the CDIO standards must be updated. This lead to a formal proposal for the CDIO 3.0 standard in 2019 (Malmqvist, *et al.*, 2019), and finalised in 2020 (Malmqvist, *et al.*, 2020). The latest CDIO standards are presented in Table 1.

Table 1: CDIO 3.0 standards and optional standards (Malmqvist, *et al.*, 2020).

Standard 1	The context
Standard 2	Learning outcomes
Standard 3	Integrated curriculum
Standard 4	Introduction to Engineering
Standard 5	Design-implement experiences
Standard 6	Engineering learning workspaces
Standard 7	Integrated learning experiences
Standard 8	Active learning
Standard 9	Enhancement of faculty competence
Standard 10	Enhancement of faculty teaching competence
Standard 11	Learning assessment
Standard 12	Program evaluation
Optional Standard 1	Sustainable development
Optional Standard 2	Simulation-based mathematics
Optional Standard 3	Engineering entrepreneurship
Optional Standard 4	Internationalization & mobility

The fundamental aims of the CDIO initiative are threefold (Crawley, *et al.*, 2008): (i) master a deeper working knowledge of technical fundaments; (ii) lead in the creation and operation of new products, processes and systems; and (iii) understand the importance of strategic impact of research and technological developments on society.

To achieve these objectives, the CDIO initiative heavily relies on the completion of design-build-test projects, and its pedagogy does overlap with other established theories. These include problem-based learning and real-world learning. Yet, subtle differences do exist, and will be clarified in Sections 2.2 and 2.3 to help identify where the CDIO principles were applied but potentially not identified as such in the case studies presented in Section 3.

2.2 CDIO V PROBLEM-BASED LEARNING

Problem-based learning is not an engineering specific pedagogy. In fact, it was developed in the 1950s for the medical field (Barrows, 1984; Wood, 2003). Problem-based learning focuses on self-directed learning to enable ownership of the learning process by the students, with academics in a facilitator position. The learning principles, depicted in Figure 1, are centred around cognitive and collaborative skills, and a practical and interdisciplinary approach. These fundamental skills have made problem-based learning attractive for engineering education (De Graaf and Komos, 2003). Research in yacht engineering education has also identified these skills as supporting student employability (Barkley, 2012; Souppez, 2017). Problem-based learning is therefore commonly found and constitutes a relevant pedagogy in both engineering and naval architecture education.

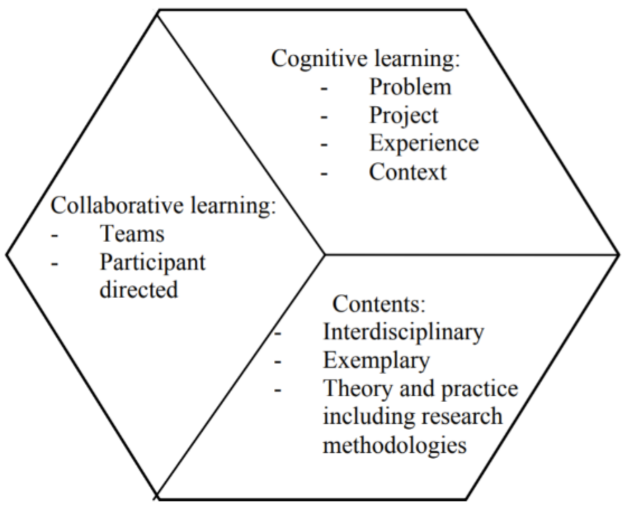

Figure 1. Problem-based learning principles (Kolmos, *et al.*, 2009).

The differences between CDIO and problem-based learning has been discussed by Edstrom and Kolmos (2014). While both practices aim to develop professional skills, problem-based learning arises from the learning process, whereas CDIO revolves around the outcome. A further attribute of the CDIO initiative is the practical aspect of problem-solving, namely the *implement* and *operate* phases. The physical implementation of the solution and its operation are fundamental to the CDIO initiative, but not required in problem-based learning. The former is therefore more oriented towards engineering education, echoing the initial CDIO objective to develop better industry-ready practical engineers, fit for the real-world. This justifies the need to further evaluate CDIO against real-world learning.

2.3 CDIO v REAL WORLD LEARNING

The idea of an authentic learning activity (Brown, *et al.*, 1988), leading to an authentic assessment (Wiggins, 1990) has gained significant momentum in recent years. Archer *et al.* (2021) recognised real-world learning as an authentic assessment experience, and conceptualised real-world learning, as depicted in Figure 2.

The underpinning aim of real-world learning, namely, to develop employability skills through authentic assessment, is common to CDIO. The scope of real-world learning, while applicable to engineering and naval architecture education alike, is however much broader. Contrarily to problem-based learning, real-world learning is, like CDIO, focussed on the outcome. However, this does not necessarily imply a physical build and test project. Indeed, many of the skills advocated by real-world learning are *soft* or *invisible*. This is, again, what sets the CDIO initiative apart: the physical implementation of a design, and its operation.

The CDIO initiative, therefore, standard out by its design-build-test philosophy, particularly relevant to engineering education. This will be a vital attribute to identify CDIO-type projects in the literature, which may not have been recognised. Indeed, the paper aims to demonstrate that, although unidentified as such, the CDIO approach has been present in the yacht and ship design field, and offers multiple benefits to support the education and professional development of engineers.

3. CASE STUDIES

In this section, an example CDIO project from the mechanical engineering discipline is presented in Section 3.1 as a benchmark. This case study is a wind turbine CDIO project conducted at Aston University. Then, four international naval architecture case studies will be discussed, namely:

- the *egg rescue boat* at the University of Liege (Sec. 3.2), by Rigo, *et al.* (2015);
- the *remote operated vehicle* at University College London (Sec. 3.3), by Anderlini, *et al.* (2018);
- the *hull design* at Olin College of Engineering (Sec. 3.4), by Dusek, *et al.* (2018); and
- the *model yacht race* at Solent University (Sec. 3.5), by Archer, *et al.* (2021).

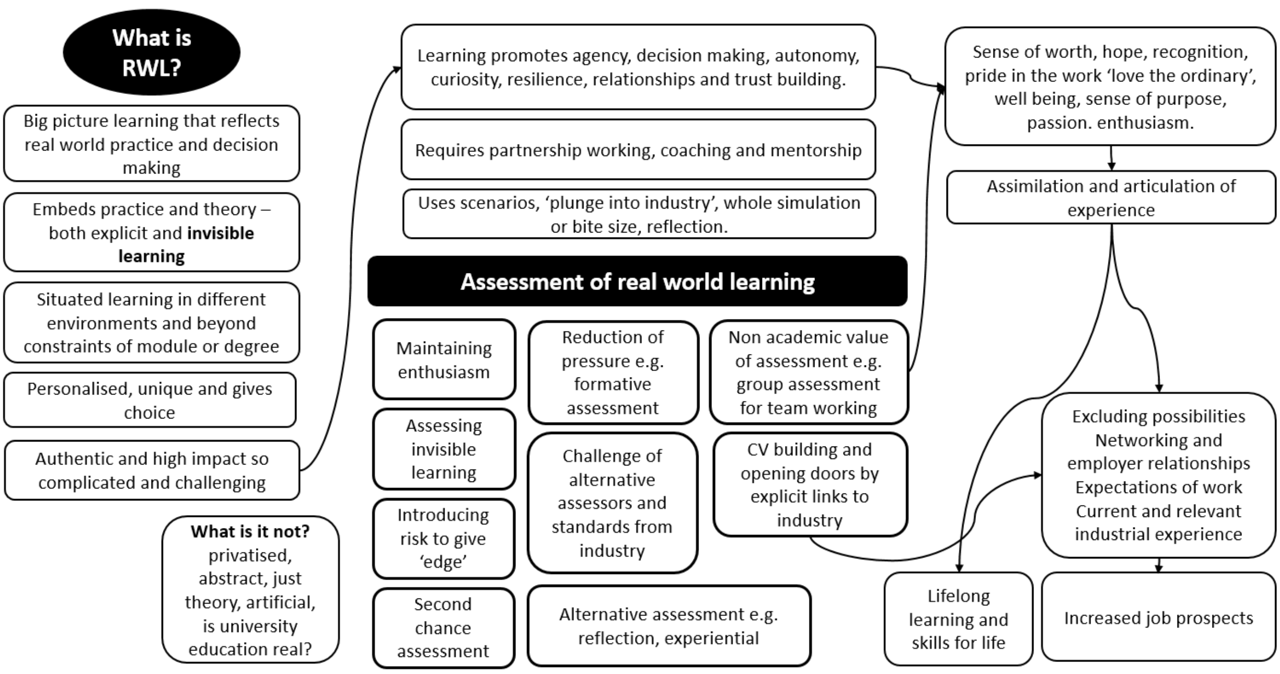

Figure 2. Real world learning concept map (Archer, *et al.*, 2021).

3.1 BENCHMARK: EXAMPLE CDIO IN MECHANICAL ENGINEERING

The CDIO initiative has been adopted in hundreds of mechanical engineering courses worldwide (Crawley, *et al.*, 2011). This is, for instance, a key pedagogical tool at Aston University, UK, where four distinct CDIO projects are undertaken in the first two years of the BEng Mechanical Engineering, totalling half of the credits over these two years. One example project is the design, build and test of a wind turbine, taking place in the second semester of the first year.

Early on in the process, students are exposed to an accelerated version of the project, having to conceive, design, build and test a small scale wind turbine, as depicted in Figure 3, using basic and inexpensive consumables. The operational phase of CDIO takes the form of an experiment to assess how much energy is generated. The wind turbine is exposed to the wind generated by a fan; the time taken to raise a given mass attached to the turbine's hub by a string is recorded, and the energy produced calculated.

The accelerated activity introduces the theoretical concepts that will support students throughout the rest of the semester. The activity also provides an opportunity to conceptualise design options, before undertaking the full design. Students will then manufacture a larger scale turbine, as shown in Figure 4. The testing process remains identical to the one introduced in the accelerated activity: the turbines are lined up on campus, and the energy produced is calculated from the time taken to raise a given mass.

Figure 3. Model scale wind turbine as an early accelerated CDIO activity.

Figure 4. Final wind turbine at the end of the CDIO module.

A complete CDIO project is therefore undertaken, with the conceptualisation, design, implementation, and operation of a wind turbine. It is worth nothing that both the accelerated activity and final larger scale wind turbine constitute CDIO activities, each with a different time and physical scale. This will be particularly relevant to Case Study 1 (Sec. 3.2).

3.2 CASE STUDY 1: EGG RESCUE BOAT (RIGO, *ET AL.*, 2015)

The EMSHIP+ master degree is part of the prestigious Erasmus Mundus program, and is a postgraduate qualification in ship and offshore structures. The program was detailed by Rigo *et al.* (2015) and its pedagogy further discussed by Souppez (2018). It features a consortium or leading worldwide Universities, with a particular focus on international mobility. Indeed, students are expected to study in three different European countries over three semesters, with the addition of an industry placement worldwide. Students are recruited from a range of engineering disciplines, but not specifically naval architecture. Therefore, an introduction to the fundamental principles is necessary.

As part of the student's induction and introduction to naval architecture at the University of Liege, Belgium, an egg rescue boat activity has been devised. In groups, the students are to design and build a rescue boat with the sole aim of protecting an egg located inside. The activity is used as a platform to introduce concepts such as buoyancy, stability, impact loads, structural design and ship construction. The crafts are then tested by launching them from a progressively higher and steeper ramp, depicted in Figure 5. The craft with the last unbroken egg is deemed the winner.

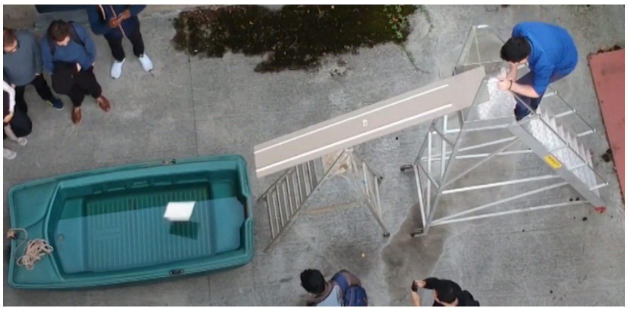

Figure 5. Egg rescue boat testing (EMship+, 2019).

While conducted over a few hours only, thereby represented an accelerated activity, it fully embodies the fundamental principles of the CDIO Initiative. Indeed, the design-build-test activity is integrated in the curriculum to provide an introduction to the necessary engineering principles, while representing and engaging and active learning experience. This further lays the foundations of the engineering principles students will go on to study in more depth. The early practical experience also provides a practical introduction to model making and testing, which the students will later put into practice when manufacturing towing tank testing models and performing resistance tests.

3.3 CASE STUDY 2: REMOTELY OPERATED VEHICLE (ANDERLINI, *ET AL.*, 2018)

The design, build and test of a remotely operated vehicle (ROV) constitutes a 2nd year coursework as part of the Ocean Engineering module at University College London, UK. The authors note that the Ocean Engineering module is not part of a naval architecture curriculum, but instead, is aiming to attract students into the field of naval architecture once they reach Master level. As such, the module is very much intended to teach fundamental concepts and offer an active learning experience. Interestingly, the authors first acknowledge the inspiration for the project as being an outreach activity (Nelson, *et al.*, 2015) originating from the MIT, *i.e.* the birth institution of CDIO.

Through the design of the module, the authors aim to *'maximise the range of different design options to foster students' innovation',* thereby offering the opportunity to develop the *conceive* and *design* phases of the project. The ROV project is further presented as a *'design and build project'*. A strong emphasis is also placed on the testing of the design during a competition, or test day. As such, all four phases of the CDIO initiative are featured. An example of the ROV designed, built and tested is presented in Figure 6.

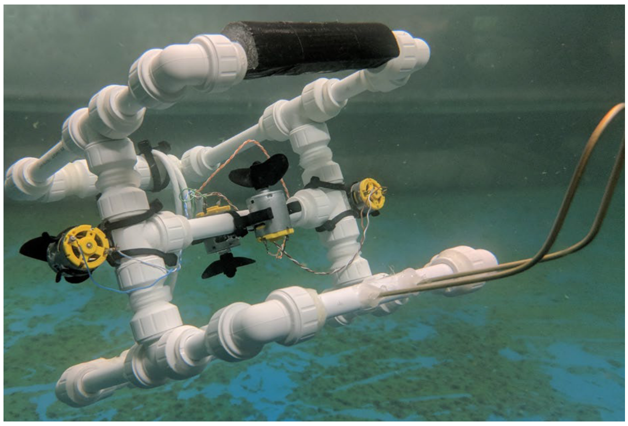

Figure 6. ROV design being tested
(Anderlini, *et al.*, 2018)

Student feedback reported by the authors highlighted the design, build and operation of the ROV was central to their learning experience. The authors also identified the development of staff as a key recommendation for future improvements, thereby aligning with additional core CDIO principles (*cf.* Standard 9 in Table 1). Overall, the ROV project described by Anderlini *et al.* (2018) demonstrates the main characteristics and outcomes of a CDIO activity ran over a semester.

3.4 CASE STUDY 3: HULL DESIGN (DUSEK, *ET AL.*, 2018)

The Quantitative Engineering Analysis module at Olin College of Engineering, US, provides an opportunity for students to design, build and test a hull. The authors characterize this activity as '*project-based-learning*' experience on several occasions, as well as a '*real-world problem*', with '*real-world applications*'. Both these theories are often associated, or confused with, the CDIO initiative, as previously identified in Sections 2.2 and 2.3. Indeed, while the activity present by Dusek *et al.* (2018) does indeed represent a problem-based learning experience with an authentic assessment leading a real-world learning experience, the specifics of the project, and its focus on the implementation of the designs and their tests makes it a great example of an unrecognized CDIO module.

An accelerated activity is undertaken on the first day to introduce students to fundamental naval architecture principles, namely buoyancy and angle of vanishing stability. As per the accelerated benchmark activity introduced in Section 3.1, this is conducted over a short time frame, at a smaller scale, and with more rudimentary materials. The accelerated activity is depicted in Figure 7.

Building on the accelerated activity, students proceed to conceive and develop a more refined design, with further theory being introduced throughout the module. Manufacturing with more advanced materials and techniques is undertaken, and the experience culminates

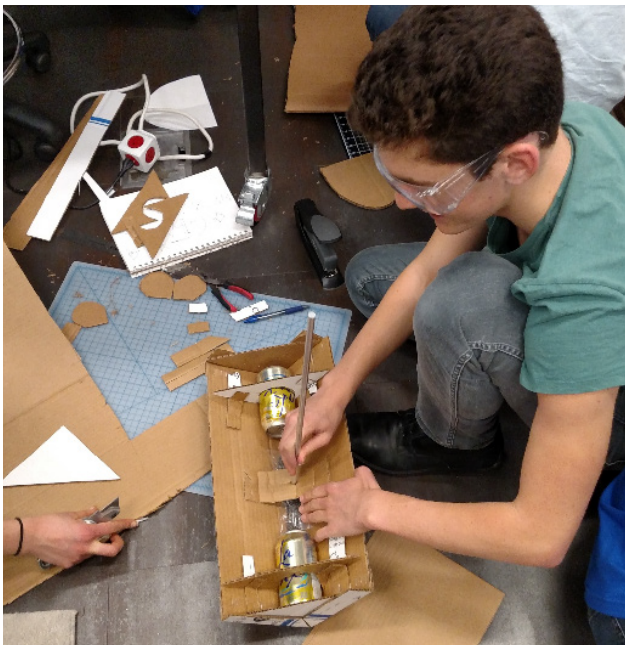

Figure 7. First day accelerated design-build-test activity (Dusek, *et al.*, 2018).

with the testing of the cargo carrying capacity and stability of the hulls, as shown in Figure 8.

The module on which this case study is based aims to integrate introductory-level mathematics, physics, and engineering, while also making use of Matlab as a simulation-based tool (*cf.* Optional Standard 2 in Table 1) for stability analysis. Both an accelerated and a module-long design-build-test project are completed. The active learning dimension is emphasised in order to foster a high level of student engagement by placing it in the context of an exciting, relevant, and tangible engineering challenge, while promoting collaborative analysis of key concepts. These benefits have also been identified by students, as reported by Dusek, *et al.* (2018). As such, the intent and delivery of the module are aligned with the CDIO

Figure 8. Final testing day once the hulls had been analysed, designed, built, and tested (Dusek, *et al.*, 2018).

initiative, and both the accelerated activity and module-long one represent great examples of CDIO activities for naval architecture education.

3.5 CASE STUDY 4: MODEL YACHT RACE (ARCHER, *ET AL.*, 2021)

The model yacht race is part of the 1st year of the BEng Yacht and Powercraft Design at Solent University, UK. This assessment is reported by Archer *et al.* (2021) as an example of real-world learning.

Similar to the benchmark (Sec. 3.1) and Case Study 3 (Sec. 3.4), two activities are conducted: an accelerated and a module-long one. The accelerated activity, depicted in Figure 9, is part of the induction week (as in Case Study 1, see Sec. 3.2), and promotes team bonding while introducing key sailing yacht design concepts. Students manufacture a small scale sailing catamaran, and engage in a race over a 4 m water tank.

Figure 9. First day accelerated design-build-test activity (Souppez, 2018).

The module is then structured so that student can conceive and design a model yacht, with a length circa 700 mm, draft of 300 mm, and air draft of 1500 mm. These are fully designed in CAD, before being manufactured in either composites or wooden strips, see Figure 10 (a). Lastly, one of the assessed components is the performance during the race day, shown in Figure 10 (b).

The argument made by Archer *et al.* (2021) that this represents a real-world learning experience is indeed correct. However, the significant emphasis on the design, implementation and operation make this project a clear CDIO one. The parallels with the benchmark (Sec. 3.1), including the accelerated activity to introduce the principles then supporting the longer larger scale project are also evident. This case study, therefore, represent another example of an unidentified application of the CDIO initiative in yacht design education.

Figure 10. Model yachts once built (a) and being tested on race day (b).

3.6 CDIO FOR NAVAL ARCHITECTURE EDUCATION

The four international case studies presented (Rigo, *et al.*, 2015; Anderlini, *et al.*, 2018; Dusek, *et al.*, 2018; Archer, *et al.*, 2021), across both undergraduate and postgraduate courses, have evidenced the presence, although unrecognised as such, of the CDIO initiative in the education of naval architects. Overlaps with other established pedagogies, such as problem-based learning and real-world learning have been identified. But the implementation and operation of practical, physical solutions to an engineering problem, fulfils the intent of the CDIO initiative, and yields its educational benefits. This was noted in the various case studies presented: an increased engagement and student satisfaction resulted from the design-build-test project.

The use of the CDIO initiative further supports the experiential learning experience of students (Michaeli, *et al.*, 2015; Vankov and Vankova, 2015) to maximise employability prospects. All of these have been identified a core to the education and development of future yacht and ship designers (Barkley, 2012; Souppez, 2015; Souppez, 2018). A very strong case can therefore be made for employing a CDIO approach in current and new naval architecture courses. This is even more relevant as student satisfaction and employability prospects are more than ever vital components and key metrics in higher education.

Moreover, the versatility of the CDIO approach makes it suitable for both short introductory and team bonding activities (*e.g.*: Case Study 1), as well as semester-long modules (*e.g.*: Case Study 2). The former case would represent an easy and inexpensive pilot study for courses and institutions wishing to pilot and experiment with the CDIO initiative. However, a combination of both, with an accelerated activity to introduce a more advanced semester-long one appears more common (*e.g.*: Benchmark, Case Study 3 and Case Study 4). This is also recommended as a better pedagogical approach.

3.7 GUIDELINES TO IMPLEMENTING CDIO IN NAVAL ARCHITECTURE EDUCATION

Section 3.6 identified CDIO has a relevant practice for the education of maritime engineers and naval architects. Here, practical guidelines to facilitate the implementation of CDIO are provided.

First, the *CDIO implementation toolkit* (CDIO, 2023) has been devised for the purpose of supporting interested institutions and individuals. The background and context are introduced, building on the theory of Crawley *et al.* (2007). Initial advice and case studies are then tackled, with respect to the following: (i) identifying learning objectives for assessment, (ii) modifying engineering curriculum, (iii) recommendations for learning and teaching practices, and (iv) examples of design-build-test projects. These, however, are primarily intended for mechanical engineering courses. Hence, the present paper and case studies offers an insight into maritime applications of CDIO.

Then, to experiment with this pedagogy, short introductory activities (*cf.* case studies 1, 3 and 4) offer a low-cost, low-risk, high-reward approach. These activities can be easily implemented, and staff and student feedback may provide the basis for a larger scale adoption. At this stage, the facilities available to an institution will drive the type and scale of CDIO projects that can be implemented. However, while case studies 2 and 4 employ large facilities, case studies 1 and 3 demonstrate that these are not essential to apply the CDIO principles and associated outcomes.

Lastly, the *CDIO implementation toolkit* (CDIO, 2023) emphasise the opportunities and support available by reaching out to institutions and individuals with CDIO modules. In the specific context of maritime engineering and naval architectures, the authors would be delighted to lend their expertise to the development of novel CDIO programs.

4. CONCLUSIONS

The Conceive Design Implement Operate initiative is an innovative engineering education framework well-established in engineering disciplines such as mechanical engineering. Whilst it overlaps with pedagogical approaches such as problem-based learning and real-word learning, it sets itself apart thanks to its applied approach, centred around design-build-test projects. Despite its popularity in mechanical engineering worldwide, the CDIO approach remains absent from the pedagogical tools employed in yacht and ship design education curricula.

Four international case studies at undergraduate and postgraduate level have been studied. In all instances, these modern naval architecture courses have been shown to employ an approach akin to that of the CDIO initiative, often only identified as problem based-learning or real-world learning. This paper showed that, even though not recognised as such at the time by the authors, the four case studies under consideration have been employing a CDIO approach, aligned with core CDIO characteristics. Furthermore, this paper identified the CDIO initiative as a relevant pedagogy for the development of novel courses and activities, and provided guidelines for its implementation.

It is anticipated that this first recognition of the use of the CDIO initiative in naval architecture will contribute to formalizing the implementation of the CDIO pedagogy in this field, as well as enable greater synergies between the various disciplines of engineering education.

5. REFERENCES

1. ANDERLINI, E., BRADBEER, N., SAVAGE, C. and THOMAS, G. (2018) *Ocean engineering minor: The use of ROVs for the teaching of ocean engineering.* RINA Education & Professional Development of Engineers in the Maritime Industry, London, UK.
2. ARCHER, M., MORLEY, D. A. and SOUPPEZ, J.-B.R.G. (2021) *Real world learning and authentic assessment*. In: D. A. Morley and M. G. Jamil, eds. *Applied Pedagogies for Higher Education.* Palgrave Macmillan, Cham., pp. 323-341. https://doi.org/10.1007/978-3-030-46951-1_14
3. BARKLEY, G. (2012) *Attracting & equipping yacht design and production graduates for employment in today's yacht design and manufacturing industry.* RINA Seminar of Education and Professional Development, Southampton, UK.
4. BARROWS, H. S. (1984) *A specific problem-based, self-directed learning method designed to teach medical problem-solving skills, and enhance knowledge retention and recall.* Tutorials in Problem-Based :earning, pp. 16-32.
5. BENNEDSEN, J., GEORGSSON, F. and KONTIO, J. (2016) *Updated Rubric for Self-evaluation (v. 2.1).* The 12th International CDIO Conference, Turku, Finland
6. BRODEUR, D. and CRAWLEY, E. F. (2005) *Program evaluation aligned with the CDIO standards.* American Society for Engineering Education - Annual Conference & Exposition, Portland, Oregon, US. http://doi.org/10.18260/1-2--15474
7. BROWN, J., COLLINS, A. and DUGUID, P. (1988). *Situated cognition and the culture of learning.* Institute for Research on learning, Palo Alto, Clifornia, US.
8. CDIO (2023). *The CDIO Implementation Kit*. [Online] Available at: http://www.cdio.org/implementation-kit-ikit (Accessed 14/01/23).
9. CRAWLEY, E. F., BRODEUR, D. R., and SODERHOLM D. H. (2008) *The education of future aeronautical engineers: conceiving, designing, implementing, and operating*. Journal of Science Education and Technology, 17(2) pp. 138-151. https://doi.org/10.1007/s10956-008-9088-4
10. CRAWLEY, E. F., MALMQVIST, J., OSTLUND, S., and BODEUR, D. R. (2007) *Rethinking engineering education: The CDIO approach.* 1st ed. New York, USA: Springer-Verlag.
11. CRAWLEY, E. F., MALMQVIST, J., LUCAS, W. A., and BODEUR, D. R. (2011) *The CDIO syllabus v2.0 an updated statement of goals for engineering education.* Proceedings of the 7th International CDIO Conference, Copenhagen, Denmark.
12. CRAWLEY, E. F., MALMQVIST, J., OSTLUND, S., and BODEUR, D. R. (2014) *Rethinking engineering education: The CDIO approach.* 2nd ed. New York, USA: Springer. https://doi.org/10.1007/978-0-387-38290-6
13. DE GRAAF, E. and KOMOS, A. (2003) *Characteristics of problem-based learning*. International Journal Of Engineering Education, 19(5), pp. 657-662.
14. DUSEK, J., O'BRIEN, J., CHRISTIANSON, R., GEDDES, J., LEE, C., and SOMERVILLE, M. (2018) *Fostering student excitement for marine engineering in fundament engineering courses.* Oceans 2018 MTS/IEEE, Charleston, South Carolina, US. pp. 1-9. 10.1109/OCEANS.2018.8604578
15. EDSTROM, K. and KOLMOS, A. (2014) *PBL and CDIO: complementary models of engineering education development.* European Journal of Engineering Education 46(6), pp. 889-907. https://doi.org/10.1080/03043797.2014.895703
16. EMship+ (2019) *Rescue boat contest - Emship 2019 - welcome to Liege.* [Online] Available at: https://tinyurl.com/273ev2un (Accessed 15/03/22).

17. KOLMOS, A., DE GRAAFF, E. and DU, X. (2009) *Diversity of PBL–PBL learning principles and models*. Research on PBL Practice in Engineering Education, pp. 9-21. https://doi.org/10.1163/9789087909321_003
18. MALMQVIST, J., EDSTRÖM, K., GUNNARSSON, S. and ÖSTLUND, S. (2006) *Use of CDIO Standards in Swedish national evaluation of engineering educational programs.* Proceedings 1st Annual CDIO Conference, Kingston, Ontario, Canada, pp. 134-137.
19. MALMQVIST, J., EDSTRÖM, K. and HUGO, R. (2017) *A proposal for introducing optional CDIO standards.* Proceedings of the 13th International CDIO conference, Calgary, Canada, pp. 18-22.
20. MALMQVIST, J., EDSTROM, K. and ROSEN, A. (2020) *CDIO Standards 3.0 - Updates to teh core CDIO standards.* Proceedings of the 16th International CDIO Conference, Chalmers, Sweden.
21. MALMQVIST, J., WEDEL, M K, LUNDQVIST, U., EDSTROM, K., ROSEN, A., ASTRUP, T. F., VIGILD, M., HUSSMAN, P. M., GROM, A., LYNG, R., GUNNARSSON, S., HUAY, H. L.-W. K., and KAMP, A. (2019) *Towards CDIO standards 3.0.* Proceedings of the 15th International CDIO Conference, Aarhus, Denmark, pp. 512-529.
22. MICHAELI, J., MOSES, P., HOU, G., and AYALA, O. (2015) *Developing a naval engineering workforce through undergraduate research and experiential learning.* RINA Education & Professional Development of Engineers in the Maritime Industry, London, UK.
23. NELSON, S. G., COOPER, K. B. and DJAPIC, V. (2015) *SeaPerch: How a start-up hands-on robotics activity grew into a national program.* MTS/IEEE OCEANS 2015 - Discovering Sustainable Ocean Enginery for a New World, Genova, Italy.
24. RIGO, P., BRONSART, R. and TACZALA, M. (2015) *EMship+, a unique european master programme in ship & offshore structures.* RINA Education & Professional Development of Engineers in the Maritime Industry, London, UK.
25. SOUPPEZ, J.-B. R. G. (2015) *A student's take on education in the maritime industry*. RINA Education & Professional Development of Engineers in the Maritime Industry, London, UK.
26. SOUPPEZ, J.-B. R. G. (2017) *Interdisciplinary pedagogy: A maritime case study.* Dialogue: Journal of Learning and Teaching, vol. 2016/2017, pp. 37-44.
27. SOUPPEZ, J.-B. R. G. (2018) *Anchoring the experience of highly diverse students on the EMship+ master: all aboard.* Dialogue: Journal of Learning and Teaching, vol. 2017/2018, pp. 93-108.
28. SOUPPEZ, J.-B. R. G. (2018) *Learning and Teaching in Yacht Engineering Education.* RINA Education & Professional Development of Engineers in the Maritime Industry, London, UK.
29. VANKOV, P, and VANKOVA, D. (2015) *Experience-based innovative programme in Varna, Bulgaria*. RINA Education & Professional Development of Engineers in the Maritime Industry, London, UK.
30. WIGGINS, G. (1990) *The case for authentic assessment.* Practical Assessment, Research and Evaluation, vol 2, article 2. https://doi.org/10.7275/ffb1-mm19
31. WOOD, D. F. (2003) *Problem based learning.* BMJ Publishing Group Ltd, 326(7384), pp. 328-330. http://doi.org/10.1136/bmj.326.7384.328