Agile Learning in Product Development

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Introduction

The agile method originating from the software industry responds to the changing nature of client and project requirements. It is, more than ever, relevant in any engineering fields focusing on product design, development, and manufacturing, and serves as a timely pivot between idea formation, resource allocation, and outcome identification to cater for evolving technology needs across industry. The agile manifesto articulated in 2001 (Beck et al., 2001) outlined key elements of agile methods. These include, notably, client collaboration, expectation of changes, regular documentation and delivery, review and reflection, re-prioritisation, and short burst of efforts largely known as "sprints" for the production and refinement of prototypes. The translation of key agile practice in education in summarised in Table 1.

Table 1: A reproduced summary table of the top four attributes translated from the Agile Manifesto to the classroom environment. (Parsons and MacCallum, 2019; Stewart, et al., 2009)

Value	Agile Manifesto	Agile Manifesto in Education
1	Individuals and interactions, over process and tools	Students over traditional processes and tools.
2	Working software, over comprehensive documentation	Working projects over comprehensive documents.
3	Customer collaboration, over contract negotiation.	Student and instructor collaboration over rigid course syllabi.
4	Responding to change, over following a plan	Responding to feedback rather than following a regimented plan.

However, despite the advantages of the agile method, the traditional waterfall engineering approach still prevails in product design teaching. The waterfall approach has a pre-determined, linear, sequential path to product development, which is less responsive to rapidly changing client demands in the industry (Stewart, et al., 2009), but has the advantage of predictability and easy management for novice learners of product development. Indeed, the waterfall method is a common method in the teaching of product design because it suits short teaching timeframes. Completing stages of agile product development can take a long time, but a typical teaching period is only approximately 13 weeks in Australia. Within the 13 weeks, students commonly spend a significant amount of time in the beginning to orientate themselves to the project, with the plan to reserve final weeks to craft final reports and presentations. The time constraint limits a course convenor's ability to design a product development course with agile focuses. Consequently, course organisers may need to resort to limiting the scope of the project by eliminating some stages of the process.

In the pursuit of effective learning methods for product design, we argue for an agile learning design that incorporates key strengths of micro waterfall steps. In this hybrid method, initial waterfall steps are blended into a larger agile development cycle, so that educators can deliver training timely for evolving industry needs and at the same time accommodate learning components that require scaffolding. We show, in Figure 1, that in a product development cycle, there exist stages of learning that are best mapped to a typical waterfall methodology, especially initially, to suit learners' needs. The smaller milestones and deliverables can contribute to and form part of a larger agile product development life cycle. These micro waterfall steps include problem definition, design prioritisation (requirements), planning, development, testing, adjustment, and deployment, which allow for the necessary scaffolding at the start of the project to ease beginners into a project. The learners are then required to revisit these steps to refine their prototypes or initial products in an agile cycle.

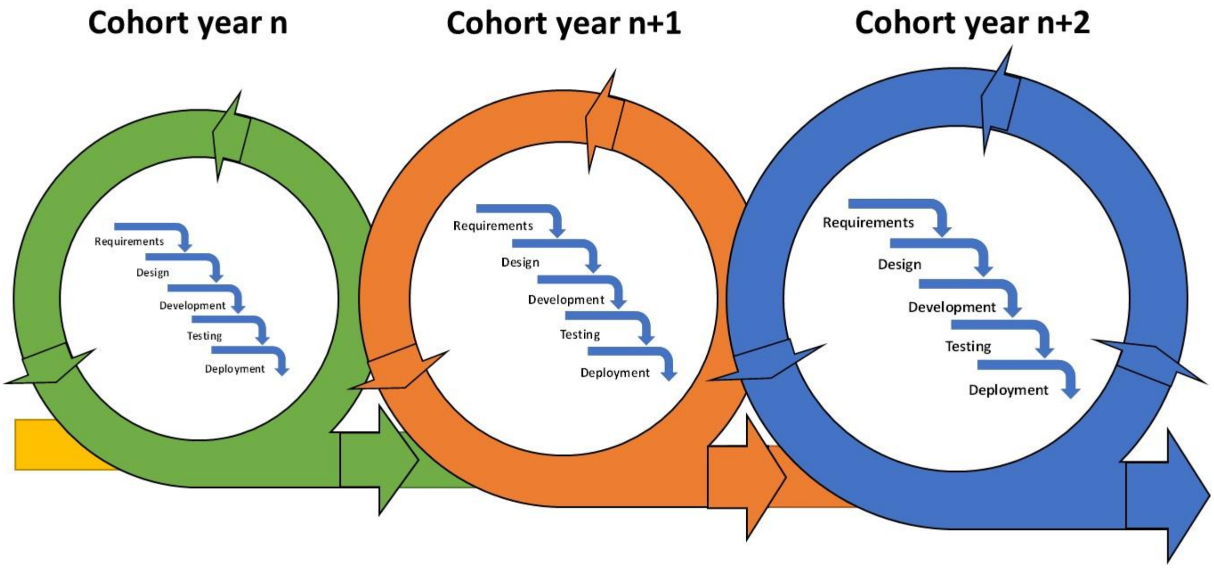


Figure 1: A hybrid Agile-waterfall model used in a mechanical engineering capstone course. Agile learning is achieved at the inter-cohort level, where students benefit from feedback and critic of previous work prior to beginning their own development cycle. The cycles are facilitated with the use of the teaching implementation reported herein.

In this learning design, time constraints can be overcome by extending the agile cycle across cohorts. Previous work performed by earlier cohort are not only used to set the expectation for quality for the next cohort, but also to form a basis of prototypes which the new cohorts can also build on or expand from. To enable this, we developed a web-based work repository which contains previous products and evaluations, to enable prior knowledge and prototypes to form a longer-term product development cycle. Here, we report the process and outcomes of this inter-cohort solution we trialled, as illustrated in **Figure 1**, to implement agile learning in a fourth-year product design unit- a capstone course of Mechanical Engineering at an Australian university.

Approach

In a final year Mechanical Engineering capstone course, teams of three to four students were tasked with integrating and applying their technical skills learnt from the prior years to develop a product, which can be a completely new project or a significant modification of an existing product. At the beginning of the course, students were first asked to visit an online repository consisting of the product design work by previous student cohorts (**Figure 2**). This website (www.MQIDEA.com) have been setup to hosts the comments, designs, and technical analysis of work submitted from the previous cohort.

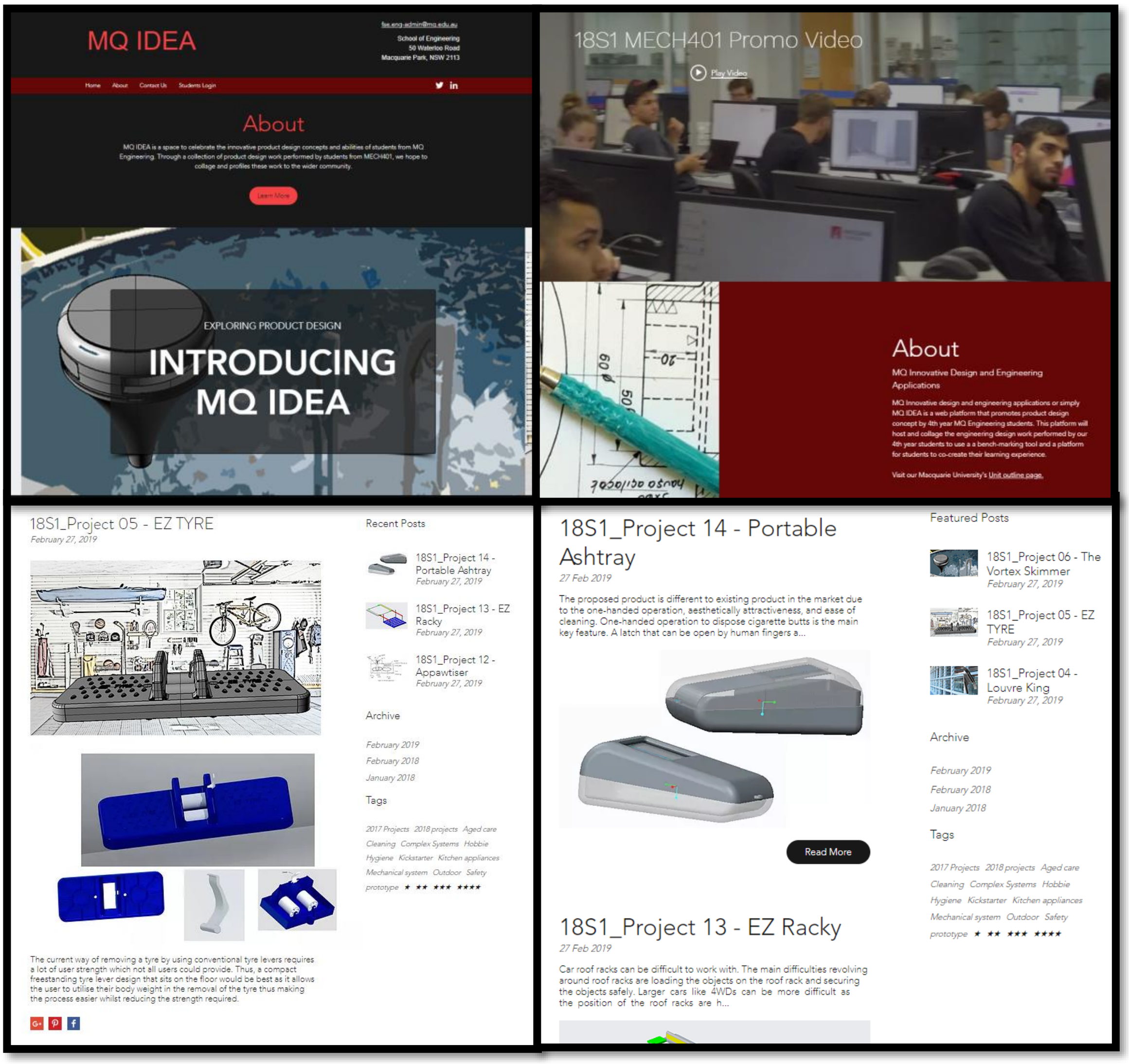


Figure 2: Teaching implantation: website repository of student work from previous offerings. (Top left to right): Introductory page, the About page, Students past work, Students past work.

Students were to rank, evaluate and critique the presented work based on four key criteria. These four categories are: Innovation, Feasibility, Excellence and Potential (**Table 2**). Their critical judgement of previous work set the level of expectation for their group to design and develop the product for the remaining semester. The previous evaluation comments were also presented, allowing students to view previous grading evaluation. In addition to the assessors' comments there were also four categories of scores given.

Table 2: Summary of the four assessment categories for the product development unit

Innovation	This represents the uniqueness of a solution (relative to other solutions in the market) to solve a problem. It could also be used to define new products that are not available in the market.
Feasibility	This represents whether the design, functionality and manufacturability of the proposed product is feasible. Note that feasibility is assessed solely on the information that has been presented by student groups. Hence, a product that

	is deemed to be easily manufactured but not well explained in report will also score low in feasibility.
Excellence	This represents how detail is the design and the general quality of the report.
Potential	This represents how potential is it for the product to be commercialised. This is based on the collective opinion of the reviewers. A poor design may receive a high score on this component given that the basic concept is novel and is able to fill a critical product gap in the marketplace.

The rest of the semester consisted of lectures, field trips, and scaffolded tutorials and assignments which collectively are aimed to scaffold the different stages of the product development cycle. The topics involved in these teaching activities included customer validation, brain storming and design variance, financial forecasting, design for manufacturing and assembly and value preposition. The student groups periodically submitted milestone deliverables for their product development, such as conceptual design, failure mode, effect analysis, and financial forecasting. At every stage, student groups were given formative feedback and comments. The students could change their product idea any time before the halfway mark of the semester, with the condition that they repeated all the required work leading up to that change. These submissions contributed to their final design report and final "shark-tank" pitch. The Shark tank pitches were a short presentation to a panel of industry experts and potential "venture capitalist". During this presentation, they were evaluated on their value preposition and presentation skill. In essence, over the 13 weeks, students undertook a product design journey from problem identification, to conceptual designs and design variance, implementation, prototype, modification, validation, and communication.

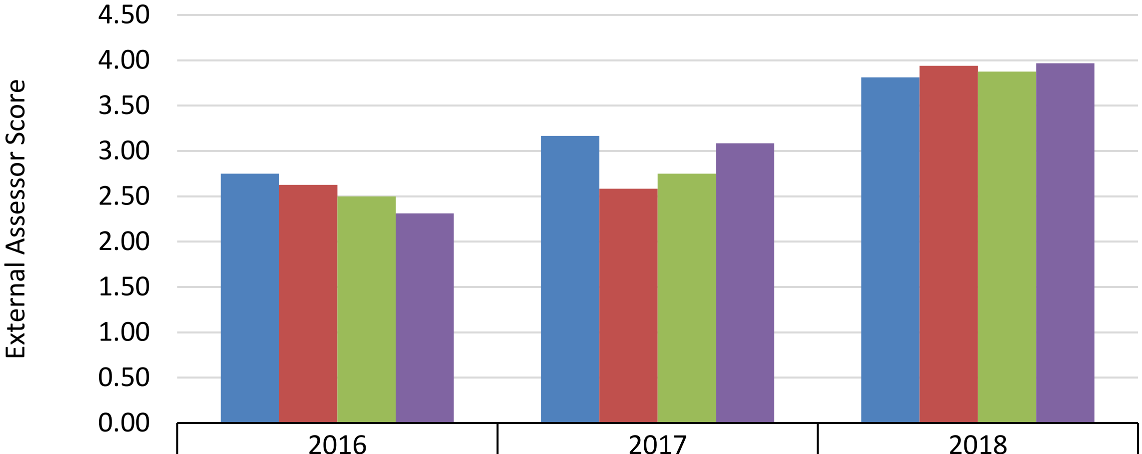
Method

To compare the effectiveness of the teaching implementation, we used two different measurements. The first was the group assessment outcomes of student cohorts between 2016 (*N*=31), 2017 (*N*=29) and 2018 (*N*=53), examined by two independent external assessors outside the course of the Unit. The products were de-identified so no year or date were included. They were then independently reviewed and evaluated by two assessors, who were experienced specialists working at prominent product design firms. They followed a marking rubric to grade the students' work. The number of reported submitted varied between the years due to enrolment. There were 4, 6, and 8 group projects in 2016, 2017, and 2018 respectively. In total, 18 design reports were analysed by the two assessors.

The second measurement was collected from student ratings on three items in a learning evaluation. These items were introduced in 2018 to capture the effect of the teaching tool to enable inter-cohort agile learning. Fifty students completed the evaluations and rated their improvement on product development understanding, creative skills, and usefulness of the web tool, based on the use of the web tool. The rating is recorded on a six-point Likert scale, with one being the lest and 6 being the most, in terms of improvement of skills, and usefulness of the tool.

Results

The results of external assessors' evaluations are summarised in Figure 3. A visibly significant improvement in quality of work can be seen in the 2018 student cohort over the 2016 and 2017 cohorts, in all four categories of innovation, feasibility, excellence, and potential. The variability of the scores between the four categories were also lower for the 2018 student cohort.



	2016	2017	2018
Innovation	2.75	3.17	3.81
Feasibility	2.63	2.58	3.94
Excellence	2.50	2.75	3.88
Potential	2.31	3.08	3.97

Figure 3: A summary of the scores given by the independent assessors for students work in the four categories. The number of submissions assessed were 4, 6 and 8 for the 2016, 2017 and 2018 cohorts, respectively. The web tool was introduced in 2018's class offering.

The students' evaluation results show that the perceived improvement of product development knowledge by using the tool went from 3.5/6.0 before the course to 4.9/6.0 after the course. Students rated the improvement of creatively by using the tool went from 3.7/6.0 before the course to 4.7/6.0 after the course. On the question of how useful the tool has been in kickstarting product development learning, the students evaluated it at 3.9/6.0. In terms of the tools' effect on kickstarting creativity skills learning, the students rated it at 3.8/6.0.

Table 3: Summary table of evaluation by students on the web tool

Teaching Activities	Most Enjoyable	Most Effective
Project assignment	1	1
Active In-class discussion	2	2
CAD & other technical analysis	3	3
Broken down assignments	4	5
Tutorial practice questions	5	4
Independent research	6	6
Lectures (In Person)	7	7
MQIDEA web platform	8	8
Lectures (Recording)	9	9

However, across all the learning activities, the web tool did not rank high on the questions of the most enjoyable and most effective activities in the course. The tool ranked 8th both on enjoyability and effectiveness. Looking at student responses, it appeared students' raking on enjoyability and effectiveness both positively associated with how hands-on or active the activities were. Although ranking did not mean the activities were not enjoyable or effective, it did indicate that there was great potential to increase interactivity of the tool, especially if the tool was to play a bigger role in learning facilitation. Some student feedbacks provided tangible directions for improvement:

“add more ideas or concepts and the lecturer tutors view on it. example, choose a product from shark tank and gave us your pros and cons”

and

“to be more detailed on feedback and have a back story/ context for each product”.

Despite these suggestions, some students also found the tool very useful in helping their understanding of product development:

“*the most useful tool to see and compare our current product with previous ones, to not make the same. Also, ideas on what is expected, accepted, or not accepted.”*

and

“Where the product was shown wit[h] a clear description of its functions, the part where the product was ranked in terms of feasibility, potential and innovation”

Discussion

Overall, following the new teaching design, coupled with the implementation of the web tool, a significant improvement is observed in terms of quality of work and enhanced consistency among design aspects. Prior to the 2018 teaching implementation, students were not able to correctly benchmark themselves against any prior standards and expectations. Incorporating previous student cohorts’ work into the agile learning design enables current students to learn specific design features from earlier student cohorts. Consistent with the student evaluation, assessors’ evaluation also showed that the tool is effective in allowing students to set the appropriate benchmark, build upon the expectations and design capabilities, and thereby increase the quality of work between the years. Our results support the observation in other studies that such online tools have significant positive impact on students’ development and appreciation of design standards (De Vere, et al., 2010).

Another benefit of seeing prior work is the opportunity to identify market gaps and design opportunities through existing products and solutions. This encourages students to see the greater contexts of problem solving, which is not just solving a problem at hand, but solving a problem in light of a range of other solutions on the market. It has been noted that identifying a market gap is a higher valued and transferable skills that needs to be incorporated in design education (Wormald, P. W., & Rodber, M., 2008).

However, at its infancy, the students’ evaluation and feedback on the web tool showed that it needed refinement to increase its perceived usefulness to students. The frequency of references to the tool may need to increase so students will revisit the tool more often during throughout the project, not just in the beginning. Students’ suggestions to provide background narratives into the previous product information and to feature final shark tank products from previous years are all good suggestions to incorporate to improve the tool. Given time, the tool will also accumulate a larger collection of products to increase diversity of products. The tool can also become more interactive to maximise its use.

It is important to point out significant limitations to this study. Given the size of the student cohort, statistical analysis is limited. Continual data collection will be useful to assist further analysis with a larger sample size. This study is also carried out in one institution only; therefore, the generalisability of the findings is limited. Cross-institutional data collection is recommended for future research.

Conclusion

In this paper, we documented a new teaching design with a web tool to facilitate long-term inter-cohort agile learning whilst incorporating waterfall method’s features for learner’s short-term developmental needs. We trialled this approach in a final year capstone product design course at an Australian University. The web tool inducted students into a 13-week period product development project. The outcomes of this approach were assessed in two parts. The first being assessment of the quality of student work by two independent external assessors across four categories: innovation, feasibility, excellence, and potential. The results indicated a marked improvement in design quality and consistency across the four categories. Students' evaluations indicated a positive recognition of the tools in improving product development knowledge and creativity skills. However, the ranking of all learning activities showed that there was room for improvement of the tool to maximise its perceived usefulness and enjoyability. Student feedback provided future directions for the web tool development, particularly in including more in-depths background information of previous product ideas.

Our agile learning design espouses the wider context of PBL approach, which has been recognised as effective in integrating knowledge and skills so students can become competent engineer (Perrent, et al., 2000; Kiernan, L., & Ledwith, A., 2014). The improvement observed in this study lends support to agile learning in PBL, where iterative feedbacks can be established between the years of offering. This addresses the challenge of product design courses, in which short timeframes prohibit iterative product design lifecycles. Our approach expediates the initial problem decomposition phase of the lifecycle to give more time for the subsequent design variance and redesign phase, which the agile cycle emphasises. The teaching implementation of an inter-cohort agile cycle, by enabling students to access prior work and set the expectations upfront, proves promising in enabling agile learning.

As standards and benchmarking expectations are increasingly recognised in design work (Cross, 2011; Dym et al., 2005), agile learning with tools to facilitate effective produce development life cycles will play a crucial role in enhancing critical, transformative skills to produce engineers for the future (Author withheld, 2018). It will also have implications for more purposive learning, where learners are guided in context with visible and explicit examples (Kek & Huijser, 2017). Future research is encouraged to provide further evidence to examine conditions that best facilitate agile learning.

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