Integration of a Product Lifecycle Management Tool to a Systems Engineering Principles Based Curriculum

Ashen De Silva[a,*], Peter Knights[a], P Ross McAree[a], Shiraz Sabdia[a] and Luigi Jules Vandi[a,b]
School of Mechanical and Mining Engineering, The University of Queensland, Brisbane, Australia[a]
Centre for Advanced Materials Processing and Manufacturing (AMPAM), The University of Queensland, Brisbane, Australia[b]
**Corresponding Author Email: ashen.desilva@uq.edu.au*

ABSTRACT

CONTEXT

In today's globalised and highly competitive engineering landscape, Product Lifecycle Management (PLM) Systems has seen increased attention due to its breadth of capabilities in serving as a centralized hub to manage product data across the lifecycle stages of a product. Due to the industrial significance it carries, it is critical to integrate PLM into curricula of universities to foster graduates prepared to take on modern day challenges in an engineering context, including understanding modern social responsibilities.

PURPOSE

This study aims to implement a multifaceted approach to integrate a PLM platform into the *Systems Engineering Principles* course, taken by third year mechanical engineering undergraduates of the University of Queensland, Brisbane, Australia. The study further aims to employ strategies to overcome issues incurred in implementing a PLM platform in an educational setting from a resources and infrastructure perspective.

METHODOLOGY

The methodology involved deployment of a state-of-the-art PLM system at the university, refining course structure to align with the learning objectives, followed by the delivery of course lectures and PLM focussed trainings. Evaluation process of the course consisted of assignments focussed on a real-world problem and were arranged in a manner to guide students to produce a concept solution consistent with systems engineering theory. Key evaluation aspects of the course included solution feasibility, work quality, teamwork, and use of the PLM platform to manage the digital workflow. The study incorporated a combination of Experiential Learning Theory (ELT) and Problem-Based Learning (PBL) to introduce foundational concepts to students and the application of systems engineering concepts to analyse and solve a real-world problem provided.

ACTUAL OUTCOMES

The results obtained by the students for course assignments throughout the semester reflected their strong grasp of both PLM tool and systems engineering principles. The PLM system maintained an availability of over 99% throughout the semester and was actively engaged with for over 12,000 hours among 230 students.

CONCLUSIONS

Based on these results, it can be concluded that strong knowledge in using an industry-grade PLM platform and a solid understanding of systems engineering principles were acquired by students and the deployment of a PLM platform on a large scale in an educational setting, was successful.

KEYWORDS

Product Lifecycle Management, Systems Engineering, PBL, ELT

Introduction

With new technological trends, tools and techniques being introduced to the industry at a rapid pace, it is important for academia to swiftly adapt to incorporate these in the curricula where applicable and possible to ensure the workforce skill gaps are closed. Product Lifecycle Management (PLM) systems, evolved from Product Data Management (PDM) systems, are one of the tools widely used in industry to manage the data and information which a product generates throughout its life. The lifecycle of a product consists of five stages in concept, detailed design, manufacturing, operation and disposal (Stark, 2022). As opposed to the capability of managing only the product data which PDM systems provided, the need of managing the entire lifecycle of a product is catered by PLM systems, of which the 'development of a product' is only a part of.

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems (INCOSE, 2015). The function of systems engineering is to guide the engineering and development of complex systems (Kossiakoff et al., 2020). As shown in Figure 1, the design of a complex system typically begins with a research-oriented phase dedicated to analysing the stakeholders needs, which then progresses through to deriving system requirements from the analysed needs to system design phase.

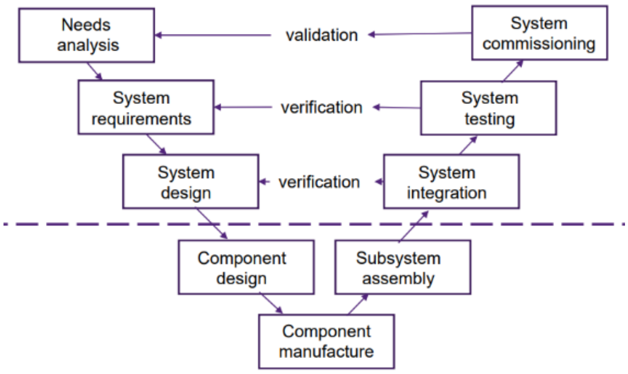

Figure 1: A Simplified variant of the 'V' diagram (Cloutier et al., 2015)

Project Management is an inherent part of systems engineering and it assists the team(s) engaged with a system across its lifecycle in setting objectives, executing, reflecting on progress made and application of corrective measures where necessary to ensure the scope of the project is met withing the agreed time and budget (Galli, 2020).

Regardless of the importance it carries, active use of PLM platforms is an aspect universities are still in initial stages, as opposed to more popular and conventional software tools such as Computer Aided Design and Manufacturing (CAD/ CAM) software. While there are universities which have taken the initiative to educate their students on the use of a PLM system, most of these efforts primarily focus on teaching PLM as a separate unit and not as a platform to support the learning of a course or courses across a program. This is also reflected in the relatively limited amount of literature available on utilizing a PLM platform as a supporting tool for a course or courses within a program.

The integration of a PLM systems into the course *Systems Engineering Principles* is expected to improve students' understanding of how such a platform aids the design of complex systems, how a PLM platform is beneficial in the later stages of the lifecycle of a system, and to make the students competent in engaging in the digital workflows associated a widely used PLM platform in the industry. As this course only deals with the concept development of a system from a systems engineering perspective, more PLM based activities are being introduced to other relevant courses in the Mechanical Engineering bachelors' program, which cater to distinct phases of the lifecycle of a system/ product. The current study also aimed to identify best practices for PLM integration in an educational setting due to the complexities involved such as the infrastructure required to deploy the system, making the system available to its users in a large scale, the resources required to administer the system, and the management of constraints due to the availability of user licenses.

This initiative uses a combination of Experiential Learning Theory (ELT) and Problem-Based Learning (PBL) approach. ELT is a method which focuses on prioritizing learning through direct experience, reflection and application of knowledge in real-world contexts (Kong, 2021) whereas Problem-based Learning (PBL) (Smith et al., 2022) is an approach where the students learn though solving a real-world problem or a case study presented to them. This combination is expected to encourage learners to reflect on their trainings and experiences, promote critical thinking, make connections between theory and practice and application of the same in a real-life scenario, fostering a more holistic and enduring learning process.

Methodology

Identification of the Course: Systems Engineering Principles

Systems Engineering Principles (MECH3610) is a 3rd year course taken by Mechanical Engineering undergraduates at the University of Queensland (UQ). The course is focussed on systems engineering design principles and their interface with project management tools and techniques. Having acquired basic CAD and CAM competencies in an earlier course, MECH3610 introduces students to a systems engineering framework to assist with capturing user requirements in order to develop concept designs towards solving complex problems, analysing manufacturing systems to improve product throughput, cost and quality and engineering project management principles.

In the course, students are presented with a real-world problem and are expected to produce a concept design to resolve the same. After a careful consideration, a ‘Concept design for a fuel-efficient container ship retrofit’ was chosen to be the project theme associated with the course for the semester in discussion. The project theme was chosen based on its relevance to the course learning objectives, its appropriate level of complexity and the availability of a diverse range of solutions, which helps prevent students from converging on a common set of conventional solutions.

Defining the Learning Objectives

The learning objectives for this course were structured to focus on the application of systems engineering principles in the context of designing, effectively managing projects as part of a team, and handling the digital workflow associated with concept design within the PLM platform. Upon successful completion of the course, students were expected to be able to:

1 Apply systems engineering principles to design

- 1.1 Apply a systems engineering framework to develop a concept design for an engineering challenge
- 1.2 Conduct a user needs analysis and develop a register of systems requirements related to the project
- 1.3 Perform a functional analysis and allocation to the design
- 1.4 Develop, evaluate and select concept designs to satisfy the system requirements
- 1.5 Manage the digital workflow associated with the concept design using Siemens Teamcenter®

2 Manage the project competently as part of a team

- 2.1 Works as a member of the team to deliver a concept report and communicate this effectively
- 2.2 Apply project management fundamentals to manage the concept design project

Deploying the PLM Platform

Siemens Teamcenter® PLM was the preferred PLM platform to be used in the course due to its global presence across industries (SIEMENS, 2024). Given the scale of the university, a four-tier architecture was used to deploy the Teamcenter® PLM platform.

As shown in the Figure 2, the architecture consists of a resource tier, an enterprise tier, a web tier and a client tier (Helu et al., 2017). In Teamcenter®, the enterprise tier manages business logic and data integration, the resource tier handles data storage and retrieval, the web tier provides web-based access to the applications and the client tier hosts the client applications and responsible for providing the interface for users interact with the system. The resource, enterprise and web tier were deployed as per the standards and the client tier was modified to match the requirements of the university, better. Teamcenter® 'Rich Client' application was selected as the preferred client for this deployment. While the most common approach used to host the client applications is physical computers such as desktops or laptops, it was decided to use the virtual desktop platform of the university, 'UQ Digital Workspace', as the facilitating platform for the client tier. This approach allowed students to log into the PLM platform at their convenience from any location, providing a full desktop experience regardless of the type of device they use or the hardware configuration of the same.

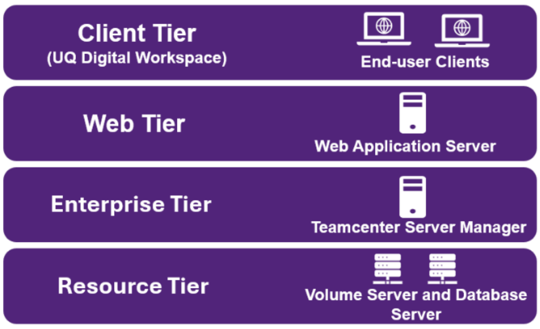

Figure 2: The architecture of Teamcenter® PLM platform deployed at the University of Queensland

Competency Assessment and Skill Development Through Teamcenter PLM Training

Upon successful completion of the course, students were expected to have developed competencies in using the Teamcenter® PLM platform in an industrial context. These competencies included proficiency in engaging with Teamcenter®, effective data management, revision control of applicable data, and project management capabilities using 'Schedule Manager' application in Teamcenter®. Additionally, students were expected to have gained expertise in requirement management with the aid of 'Requirements Manager' application, product structure and configuration management through 'Structure Manager' application and collaborative work within the PLM environment.

Designing of Course Assignments

The evaluation process for the course was designed to consist of four assignments without an end-of-semester examination. Three out of the four assignments were designed to be group assignments with one being an individual assignment. These assignments were constructed in a way that those could guide the students through the given project to deliver a concept level solution. Each of the assignments were focussed on a phase in the 'V' diagram and were formulated to have a PLM tool specific component in them to get the students to use as well as for the academics to assess the use of Teamcenter®. The late submission penalties were to be applied as per the university policies, where required.

Assignment 01 – Project Plan

Students were organised into groups of six. Assignment 01, arranged to worth 10% of the overall grade, focused on creating a work schedule to meet course milestones and assessments using the project planning functionality in Teamcenter®. The tasks for the assignment included defining a Work-breakdown Structure (WBS) for the semester, determining resource requirements for each task and allocate resources in the PLM environment, scheduling the tasks and constructing an 'S' chart to help manage the team project throughout the semester. Students were instructed to construct the 'S' chart using Microsoft® Excel, since this functionality was not feasible in Teamcenter®.

The submission of this assignment was designed to be through the PLM system. The timestamp which the PLM system assigns when an object is created and/or modified, were used to ensure timely submissions. Feedback for each of the submissions were also provided by placing a document which included the breakdown of the marks each group had obtained against the marking rubric and comments, inside the designated submission folder in Teamcenter® of each group.

Assignment 02 – System Performance Specifications

As for the Assignment 02 which weighed 10% of the overall grade, students were asked to submit a report on the university's submission platform. For the report, students were instructed to include the stakeholder analysis and system requirements for the project given. In addition to the report, it was further instructed to copy the derived requirements to a given template, upload the same as a 'Requirement Specification' into Teamcenter®.

Assignment 03 – Individual Subsystem Design

Assignment 03, worth 30% of the overall grade, was designed as an individual task. Students were instructed to ideate in groups, converge on a single solution, derive six subsystems, and each student to produce an individual report on a preferred subsystem. Students were further expected to maintain the digital footprint in Teamcenter® with regards to their subsystem and use data management and revision control functionalities in Teamcenter® to keep the digital thread between different aspects of the project.

Assignment 04 – Concept Design Report

Assignment 04 consisted of two parts. Part 'a' was a concept design report which amounted to 45% of the overall grade and part 'b' was a group presentation on their concept solution worth 5%. The students were advised to include updated sections of their stakeholder needs analysis and system requirements (from Assignment 02), system ideation and preferred configuration, verification and validation specifications, system costs (at a concept level), a sustainability analysis, and a system risk analysis in the report. The assignment also involved a PLM component where the students were tasked to build the system hierarchy of their solution in Teamcenter®. They were further asked to link the system requirements they had finalised with the appropriate subsystems within the Teamcenter® environment.

Implementing the Strategy of PLM

To ensure the reliability of the PLM platform to cater around 250 students, a pilot study was conducted with the participation of the course staff. During this phase, the staff's competence in supporting students was verified and minor adjustments were made to the system and course assignments based on the feedback received.

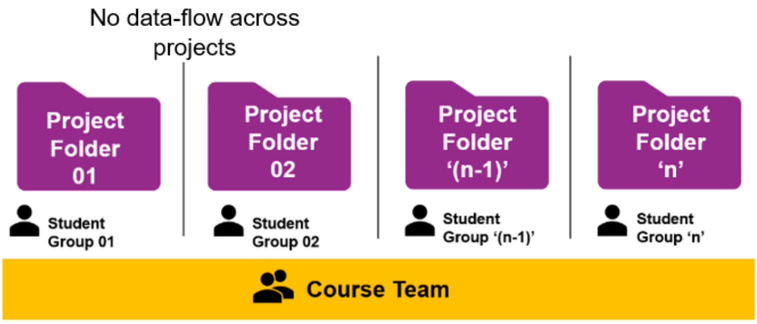

Figure 3: A schematic of the strategy used to form collaborative project spaces for student groups

Prior to the course commencement, all the students enrolled with the course and the course staff were brought into the PLM platform. Once the students had been divided into groups, their groups were created in Teamcenter® and the users were added to their respective groups accordingly. As shown in Figure 3, projects were created for each group, with user groups being assigned to their respective project folders. Access to the projects was restricted to group members, while course staff had access to all folders for monitoring, marking, and feedback. A structured folder system was provided to students to ensure a logical flow between design phases, facilitating the tracking of progress and locating submissions.

As stated in Table 1 in the Appendix, students were introduced to PLM in the second week's workshop session to reinforce their learning from lectures on the importance a PLM system as well as to familiarise them with Teamcenter®. They were given access to specific text based and video materials, developed specifically for the course and focused on giving them the required knowledge of the tool to assist them on their way to produce a concept design for their assigned project. Assignment specific demonstrations/training exercises were carried out at the beginning of each assignment phase. Students were provided with access to direct support on the use of Teamcenter® during all the workshop sessions and further support was provided through a course specific discussion forum.

Results and Discussion

In an effort to build PLM competency among engineering students at the University of Queensland, an industry-grade PLM system was integrated to MECH3610, Systems Engineering Principles course. Siemens Teamcenter® was used as the preferred platform for this initiative. Teamcenter® was established as an on-premises deployment. A four-tier architecture was used for the deployment given the expected number of users were around 250. The virtual desktop platform of the university was used to deploy the client layer of the PLM system.

The success of this study was measured based on three key metrics: technical success, student performance and student engagement.

Technical Success

The PLM platform performed well to cater to the user base of 242 (including course staff) throughout the semester. The system was expected to maintain 24-hour availability and the uptime of the system across the semester was measured at 99.63% indicating the technical success of the study.

The downtime of 0.37% was induced by operational challenges within the virtual desktop platform and the PLM server due to the high resource utilization leading up to the submission date of Assignment 01. The issue resulted in the unavailability of virtual machines to some students and unresponsive PLM sessions causing a surge in resource consumption in the server. Appropriate remedial actions were deployed at the virtual desktop platform's end to ensure accessibility to students and from the PLM system's perspective, the unresponsive sessions were cleared within a few hours and the computing resources of the server were enhanced to mitigate potential risk of the recurrence of the issue.

With the PLM platform being expected to integrate with other courses across the program and the number of users expected to grow year-by-year, it is planned to further refine the architecture to cater to around 500 users. The refinement is expected to revolve around transitioning to a multi-server architecture from the existing single-server architecture. While the expanded architecture will result in an increased maintenance effort, the change is anticipated to improve the performance of the system to facilitate more concurrent users, enhance reliability, redundancy and facilitate scalability in the future.

Since the use of virtual desktops was a new concept to some of the students, separate instructions on its use had to be provided. Positive feedback was received from the students on the use of virtual desktops as it allowed them to connect to a fully-fledged computer from a preferred location, at a time of their convenience and eliminated the high-end specifications required to run certain software.

A Frequently Asked Questions (FAQ) guide was required to be maintained throughout the semester to answer questions on the use of the PLM platform, which had not been covered in the materials provided to the students. It is planned to revise the training materials and embed this information into the existing materials prior to the next course offering.

Student Performance

The evaluation process of the course consisted of four assignments. Where applicable, the feedback for each of the assignments was provided through the PLM platform. While the students were expected to maintain the digital thread between distinct phases of the project across all the assignments through the PLM platform, the use of PLM was specifically assessed in Assignment 01 and Assignment 04. The average marks obtained by the students for the PLM component in the said relevant assignments were recorded at 86% and 92% respectively. The marking criteria for the use of PLM were designed to reflect the effectiveness of the methodologies used to deliver the PLM content and the results indicated the competencies students had gained in using Teamcenter®.

The marking rubric for Assignment 01 assessed whether the major project stages were defined, a detailed Work Breakdown Structure (WBS) was provided with appropriate granularity, identification of major tasks and milestones, allocation of resources for each task, and the suitability of the generated 'S' curve for tracking project progress. From Teamcenter® perspective, upon successful completion of the Assignment 01, students demonstrated the competency of using Schedule Manager application to manage a project.

In the Assignment 02, it was evaluated whether the key stakeholders were identified and prioritised with defined needs, lifecycle stages and environments for each stage were outlined, essential and desirable needs were determined, system requirements for performance, physical, safety, reliability, and logistical support were specified, requirements were properly codified, and a list of minimal system requirements was generated. From a Teamcenter® perspective, students demonstrated competency of using the Requirements Manager application to define requirements in the PLM platform.

The marking rubric for Assignment 03 focussed on evaluating whether functional analysis and allocation were performed, concept designs were developed, evaluated and selected to meet system requirements, the digital workflow was managed in Teamcenter® and the concept design was effectively communicated in the report. By successfully completing this assignment, students demonstrated the competency of effective collaboration with team members in the Teamcenter® PLM platform and managing data in a collaborative work environment with revision control of appropriate documents.

As per marking rubric for Assignment 04, it evaluated whether a system engineering framework was applied, concept designs were properly evaluated, digital workflow was managed in Teamcenter® and the effectiveness of the report and project management practices used. In Teamcenter, students demonstrated proficiency in using the Structure Manager application to build and manage a product structure and create links between objects for improved traceability.

Student Engagement

Teamcenter® facilitates generation of various reports based on different criteria and as per a report on the usage of the software, it was indicated that Teamcenter® had been used for 12,064.5 hours among 230 students across the semester with an average user engaging with the software for 52.45 hours. These results suggest that the system was well engaged by the userbase, further indicating a successful deployment of a PLM system on a large scale. Overall, this initiative indicated a successful integration of a PLM platform to a course focussed on Systems Engineering Principles and a successful deployment of a PLM platform on a large scale in an educational setting. As an extension of this initiative, it is planned to introduce exercises that could further leverage the CAD integration of Teamcenter®, introduce Microsoft® Viso integration to Teamcenter® to streamline the systems engineering workflow within the PLM platform and publish Teamcenter® web-based client 'Active Workspace' for an enhanced user experience, in subsequent years.

Conclusion

To the best of the Authors knowledge, this was one of the first instances where a PLM platform was integrated into a Systems Engineering-based course at this scale in a university setting and students were provided access to a PLM system outside of a laboratory environment. As a result of this initiative, a new generation of engineers is anticipated to emerge with advanced digital PLM capabilities.

We strongly advocate that proficiency in PLM concepts and workflows is a *sine qua non* for Mechanical Engineering graduates as it directly aligns with the future employability and workforce needs of Australia. In an increasingly digital and interconnected global economy, industries are relying more on sophisticated PLM systems to manage the entire lifecycle of products, from initial design through to production, maintenance and decommissioning.

By equipping students with a strong understanding of PLM, we are preparing them to meet the demands of modern industry, where the ability to efficiently manage digital workflows, collaborate across teams and ensure traceability and compliance throughout a product's lifecycle is critical. This proficiency not only makes graduates more attractive to employers in sectors such as manufacturing, engineering, but also ensures that they can contribute effectively to the innovation and competitiveness of Australian businesses on a global stage. As Australia continues to advance in fields like advanced manufacturing, aerospace and renewable energy, a workforce skilled in PLM is vital for sustaining growth and driving technological progress. Unashamedly, we want UQ graduates to be at the vanguard of these change.

Appendix

Table 1: Simplified lecture plan developed for the Systems Engineering Principles module

Week	Lecture	PBL/ELT Activity
1	Course introduction and expectations (1 hour) Systems engineering and the world of modern systems (1 hour)	Introduction to Team Assessment Release of Client Concept Design Brief Team formation Submission of Team Charter Introduction to PLM
2	The structure of complex systems The system development process (1 hour) Stakeholder needs analysis and system use cases (1 hour)	Learning the basics of PLM
3	Systems engineering management (Project stage gates, scope, cost, schedule, work-breakdown structure (WBS), critical path, and resources) (1 hour) Project costing and budget control (1 hour)	Setting up and managing projects in PLM WBS, key targets, milestones, critical path, and project controls
4	Systems requirements analysis and Functional Performance Specifications (1 hour) Digital product data and Lifecycle management (1 hour)	Identification of stakeholders, stakeholder needs and system requirements. Submission of project plan (Team 10%)
5	System architecture and functional allocation (1 hour) Design review processes (1 hour)	Development of Subsystem architecture, interface specification and allocation of functional performance specifications (FPS)
6	Ideation and design thinking (1 hour) Evaluation of concept designs (1 hour)	Ideation and detailed concept design of subsystems Submission of FPS documentation (Team 10%)
7	System integration (1 hour) System testing and evaluation (1 hour)	System integration. Consideration of subsystem interfaces FPS verification
8	System production (incl. manufacturing, assembly, commissioning) (1 hour)	Design and testing of integrated products

	Quality assurance and traceability analysis (1 hour)	Submission of subsystem concept designs (individual report 30%)
9	Design for sustainability (1 hour) Design for reliability (1 hour)	Manufacturability assessment
10	System operation and support (1 hour) Supply chain management and procurement (1 hour)	Sustainability assessment
11	Guest lecture	Assessment of operating and maintenance support risks
12	System of systems engineering and enterprise systems (1 hour) Guest lecture	Preparation of report and presentation Submission of client concept design proposal (45%)
13	Team presentations	Concept design client presentation (5%)

References

Cloutier, R., Baldwin, C., & Bone, M. A. (2015). *Systems Engineering Simplified*. CRC Press.

Galli, B. J. (2020). The Application of Systems Engineering to Project Management. *International Journal of System Dynamics Applications*, 9(1), 81–106. DOI: 10.4018/ijsda.2020010105.

Helu, M., Hedberg, T., & Barnard Feeney, A. (2017). Reference Architecture to Integrate Heterogeneous Manufacturing Systems For The Digital Thread. *CIRP Journal of Manufacturing Science and Technology*, 19, 191-195. DOI: 10.1016/j.cirpj.2017.04.002.

INCOSE. (2015). *INCOSE Systems Engineering Handbook-A Guide for Life Cycle Processes and Activities*, 4, 376.

Kong, Y. (2021). The Role of Experiential Learning on Students' Motivation and Classroom Engagement. *Frontiers in Psychology*, 12, 10–13. DOI: 10.3389/fpsyg.2021.771272.

Kossiakoff, A., Sweet, W. N., Seymour, S. J., & Biemer, S. M. (2020). *Systems Engineering Principles and Practice*. (3rd ed.). Wiley.

SIEMENS. (2024). PLM Software: Siemens Teamcenter. Retrieved June 10, 2024, from https://plm.sw.siemens.com/en-US/teamcenter.

Smith, K., Maynard, N., Berry, A., Stephenson, T., Spiteri, T., Corrigan, D., Mansfield, J., Ellerton, P., & Smith, T. (2022). Principles of Problem-Based Learning (PBL) in STEM Education: Using Expert Wisdom and Research to Frame Educational Practice. *Education Sciences*, 12(10), 728. DOI: 10.3390/educsci12100728.

Stark, J. (2022). *Product Life-cycle Management. 21st Century Paradigm for Product Realisation*. Springer Nature Switzerland.

Acknowledgement

The work of this project would not have been possible without the support of Siemens Australia who have partnered with the University of Queensland to create graduates who can meet Australia's changing workforce needs. This partnership has provided UQ with access to the Siemens Digital Industries Software suite, which includes Teamcenter® along with other software tools. The authors specifically acknowledge the vision and support of Ms. Samantha Murray, Vice President and Managing Director ANZ, Siemens Digital Industries, who has been instrumental in establishing and supporting the UQ-Siemens' partnership.

Copyright Statement