SEEING THE PROCESS: EMPOWERING STUDENTS IN DESIGN AND ENGINEERING THROUGH VISUAL FRAMEWORKS

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ABSTRACT
Since the 1960s, numerous visual models have been conceived to represent the design process and make it accessible to all stakeholders. In the educational context, these models or frameworks are meant to guide students throughout the design process, helping them understand and absorb what developing a design project entails. However, for design engineering students, we observed that they are often not fully aware of and struggle to see the methodological approach, making it difficult for them to navigate design decisions confidently. They face challenges in articulating their reasoning and justifying their choices without clearly understanding how the process unfolds. This study examines how two sequential courses in the MSc in Design & Engineering at Politecnico di Milano frame the design process within their course structure. By analysing the currently provided visual frameworks, identifying their inconsistencies, and collecting feedback on students' experiences and interpretations, we aim to provide an adaptive and cohesive visual framework able to guide students through their Design & Engineering training path and empower them to make design choices with assurance, overcoming uncertainty.

Keywords: Design engineering, visual framework, design education, design process

1 INTRODUCTION
Design has begun to be acknowledged as an academic area of inquiry only in the past 50 years. During this time, a community of scholars persevered in articulating the design process by developing systematic design methodologies and advancing the recognition of design as a discipline [1]. Moreover, organisations, consultancies, and scholars have introduced many synthesised models to establish a reciprocal knowledge and expertise interchange between design theory and practice. These visual models serve as a vehicle for communicating with other stakeholders involved in the design process and a tool for instilling design approaches in educational contexts [1]. Since we observed a lack of confidence among design engineering students in approaching mid-complexity product design projects, we decided to use visual representations of the design process to help them contextualise their design choices and identify the related critical factors hindering the alignment between the design and the project-based learning processes. Hence, we aimed to analyse how the overall process is communicated and interpreted in a high-education context, specifically in two sequential and analogous product design studio courses in the MSc in Design & Engineering of Politecnico di Milano — Product Development Design Studio (PDDS) in the first year and Final Project Work (FPW) in the second year.
To face today's global challenges and demands, design engineering students must learn to leverage humanity-centric problem-solving competencies [3, p. 451] while addressing technical feasibility and economic sustainability [4]. In the context of the PDDS and FWP courses, these interdisciplinary competencies translate into a list of Intended Learning Outcomes (ILOS) that revolve around applying design and engineering know-how, fostering awareness in decision-making, and effectively communicating design ideas. Hence, this paper aims to analyse how the design and engineering process is represented and communicated to master students to identify critical aspects, strengthen the coherence of the project-based learning educational framework adopted in the MSc in Design & Engineering (D&E), and support the achievement of the ILOs.
The following sections will examine the current visual frameworks related to the PDDS and FPW courses, analysing their differences to create an adaptive visual framework that supports and guides students throughout their learning path while considering their input.

1.1 Product Development Design Studio (PDDS): familiarising with the D&E approach

In the PDDS course taught in the first semester of the first year of the programme, groups of students with mixed educational backgrounds familiarise themselves with design research and exploration by designing a low-complexity product (i.e., lighting appliance, small household appliance), yet converging, at the end of the course, on a design concept that includes technical feasibility and manufacturing considerations. A teaching staff of three lecturers with different background knowledge and project expertise (i.e., design research, product design, mechanical engineering) tutor the project's development.

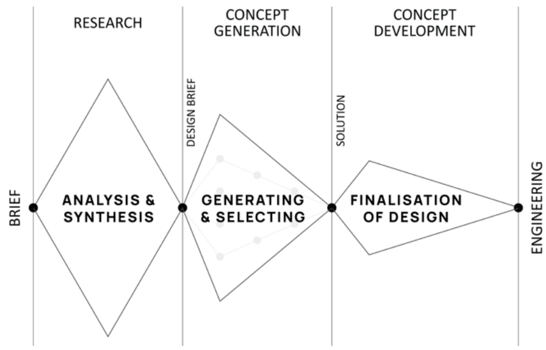

Figure 1. Visual Framework of PDDS course

The design engineering process is presented through a visual framework (Figure 1) primarily inspired by the Double Diamond model and merging design-thinking principles [2], [5] and engineering design schemes [6], [7] while encompassing research, concept generation, and concept development phases. This means integrating the iterative and divergent-convergent nature of design thinking and the procedural engineering approach to design. We noticed that integrating both perspectives often presents difficulties for students in understanding the tasks and expected deliveries.

1.2 Final Project Work (FPW): consolidating the D&E approach

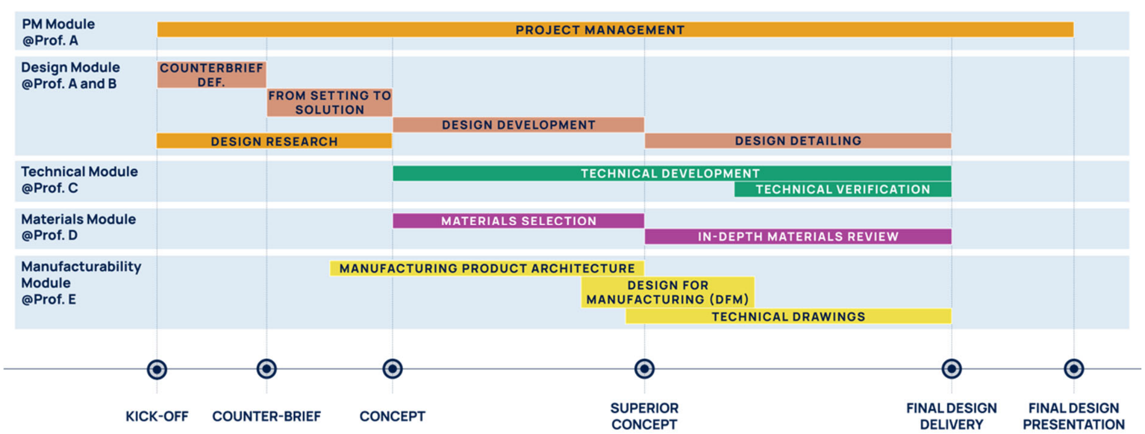

Figure 2. Visual Framework of FPW course

In the FPW course taught in the first semester of the second year, groups of students consolidate technical and overall engineering-related competencies by designing a medium-complexity product (i.e., micro-mobility vehicle, household appliances). At this stage, students are expected to have the competencies to address the design phase autonomously and effectively — encompassing research, concept generation, and concept development. A teaching staff of five lecturers with different background knowledge and project expertise (i.e., design research, product design, mechanical engineering, materials engineering, design for manufacturing) tutor the project's development.

In this case, the design engineering process is presented through a visual framework (Figure 2) like a Gantt Chart, which aims to emphasise the integration of different modules, their intertwinement, and the project milestones. Here, the emphasis on design detailing and engineering development is more significant. However, sometimes, students struggle to craft a design counter-brief, i.e., reframing the initial design brief into a more specific problem based on insights from field and desk research activities. Also, difficulties occasionally arise when selecting a concept or design solution that addresses the counter-brief. Therefore, emphasising the initial phases of design research, counter-brief and concept definition in the visualisation supports the process and limits the risk of delaying the subsequent engineering phases or producing less technically sound outcomes.

2 RESEARCH METHODS

To gather data on students' interpretations of and experiences with the proposed design engineering process, we distributed an online questionnaire via the Microsoft Forms platform among two groups of D&E students: PDDS first-year students (59 enrolled) and FPW second-year students (51 enrolled). We chose an open-ended question format to avoid influencing students' responses with preconceived ideas [8]. Instead of restricting students to selecting a specific response from a closed list, we designed a three-question open-ended questionnaire to gather more meaningful data (Table 1). The first question (Q1) explored students' prior experience with visual frameworks of the design process. The second (Q2) focused on the alignment between the proposed visualisation and the design process taught in the course. The third (Q3) examined the alignment between the course's design process and students' personal design approaches. We received 12 responses from PDDS students and 22 from FWP students, totalling 34 participants.

Table 1. Questions asked to students about the course's visualisation effectiveness

Q1	First question	Have you ever seen a visual representation of the design process before this course? If yes, which one?
Q2	Second question	How is/isn't the visualisation of the design process—including phases and outputs—coherent with the design process proposed in the course?
Q3	Third question	How is/isn't the design process proposed in the course coherent with your own approach to design projects?

3 ANALYSIS AND RESULTS

Although both courses belong to the same curricula, neither visual correlation nor complete conceptual agreement exists between them. This section presents a comparative analysis of the visual frameworks provided to students at the beginning of the PDDS (Figure 1) and FPW (Figure 2) courses. By complementing the analysis's results with the insights from a three-question open-ended questionnaire, we developed a new visual framework that can adapt to and connect both courses and empower D&E students to tackle projects more confidently, regardless of the level of complexity.

3.1 Comparative analysis of two sequential visual frameworks

To clarify the major differences between the two frameworks, Table 2 compares the PDDS visual framework (see Figure 1, hereinafter PDDS-VF) and FPW visual framework (see Figure 2, hereinafter FPW-VF) concerning focus, structure representation, and faculty alignment.

Table 2. Key differences between PDDS-VF and FPW-VF

Aspect	PDDS-VF	FPW-VF
Focus	Product meaning definition	Technical aspects and engineering development
Structure representation	A linear sequence of phases with divergence/convergence checkpoints	A linear sequence of phases within parallel thematic modules
Faculty alignment	No explicit division of roles	Clear assignment of modules and roles

While PDDS-VF emphasises product meaning through a linear process focused mainly on research and concept generation, FPW-VF prioritises technical development and manufacturability through integrated, parallel processes supported by a dedicated project management module. Moreover, FPW-VF assigns clear faculty roles depending on the specific module (i.e., design, technical, materials, manufacturing, or project management), whereas PDDS-VF lacks an explicit role division.

3.2 The perception of students on process representation coherence

We crafted three open-ended questions aimed at understanding students' knowledge and experience with design process visual frameworks (i.e., Q1), assessing their perceptions of how well the proposed framework reflected the courses' training process (i.e., Q2) and evaluating how accurately it aligned with their personal approach to design projects (i.e., Q3).

Q1: Experience with Design Process Visual Models

Approximately 80% of the respondents had encountered a visual representation before, with PDDS students most frequently referring to the Double Diamond model and FPW students to the Gantt Chart (Figure 3). FPW's formalised and technically oriented approach was generally perceived as efficient for industrial and technical projects. It is worth noting that five second-year students stated they had never seen any visual model representing the design process, suggesting that even if exposed to such representations before, they did not recognise or associate them with previous coursework.

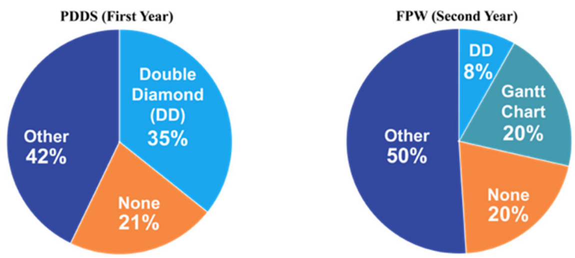

Figure 3. Students' previous encounters with design process visual frameworks

Q2: Alignment between the Visual Framework and the course's design process

Only 9% of PDDS and 19% of FPW students felt that the visualisation accurately reflected their semester-long educational path (Figure 4). PDDS students raised concerns about phase relevance and time allocation. Many "had the impression that it [the research phase] was excessive and not always useful", which likely weakened concept generation and made it more challenging and time-consuming. Nevertheless, PDDS students pointed to concept development as the most demanding phase, suggesting that "it should be visually represented as larger to reflect its real weight in the process" and that "more time would have led to more satisfactory results". FPW students appreciated the clarity of the framework in illustrating the modules' distinction. However, they felt that "steps were shown as too sequential, whereas in reality, we kept continuously editing our design through the path".

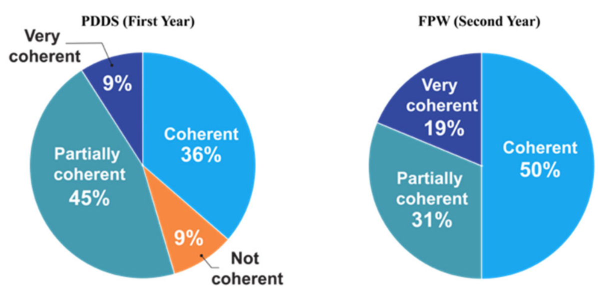

Figure 4. Degree of coherence between the visual framework and the course's process

Q3: Alignment between the course's design process and the student's approach

The distribution of students' perceptions of how their approach to design projects aligns with the courses is similar between courses (Figure 5). However, 15% of FPW students and 7% of PDDS students found the framework significantly differed from their usual methods. This might stem from FPW students' unfamiliarity with the module division (i.e., project management, design, technical, materials, and manufacturing), as they "normally include design in all phases". Despite this, most respondents recognised the structured approach as "useful for managing complex products". Furthermore, PDDS students emphasised how "the process they originally designed would have given more time for research and user pain point analysis to find insights". FPW addresses the research phase in more depth. Yet, many felt insufficient time was given to concept generation and design detailing, reinforcing that decision-making and convergence remain key challenges in D&E projects.

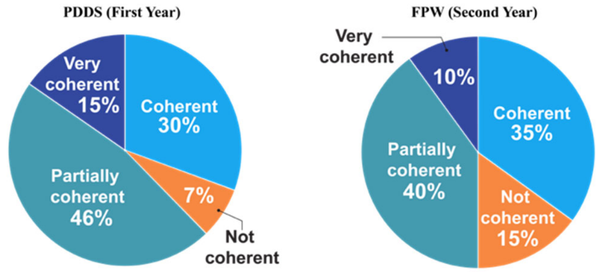

Figure 5. Degree of alignment between the courses' process and the student's approach

4 SEEING THE PROCESS

Building on the comparative analysis and students' feedback, we developed the new visual framework (see Figure 6, hereinafter DElta model), characterised by the following aspects: common vocabulary and visual language, design-driven approach, convergent engineering processes, and iterativeness and adaptiveness.

4.1 Common vocabulary and visual language

DElta framework establishes a common vocabulary and visual language, responding to the lack of connection between courses and the call for a more formalised and technically oriented structure, as expressed in responses to Q1. By establishing a shared vocabulary for each phase (i.e., analysis and synthesis, concept generation, design development, and design detailing) and milestones (i.e., design brief, counter-brief, concept, superior concept, and final design), we ensure better communication and understanding across academic years, creating a common language for both faculty and students.

4.2 Design-driven approach

To highlight the role of design as the backbone of the D&E process, as some students stressed in responses to Q3, we represented it as encompassing the engineering processes rather than as parallel and equal modules. Every technical choice is guided by and responds to design requirements, which are also integral to the design research process. Moreover, in the DElta model, design research — complemented by technical research — is a core activity that oversees and informs the entire D&E process, playing a key role at every stage and across various tasks (e.g., user-context research, technology research, and materials research), addressing the lack of depth of this phase perceived by most students. For this reason, we represented it as an all-encompassing activity spanning from the design brief to the final design milestone.

4.3 Convergent engineering processes

Rather than a rigid, linear, and parallel separation between modules (e.g., manufacturing, materials, technical), the DElta model illustrates the intertwining of development phases. Technical key phases — materials and processes and mechanical design in the case of PDDS, and functional development, materials selection, and design for manufacturing in the case of FPW — are represented as converging flows, emphasising their interdependence and collaborative relationship. With this approach, the framework maintains clarity on module differentiation, making dealing with complexity easier, while representing how they converge towards a common solution.

4.4 Iterativeness and adaptiveness

The iterative nature of the design process was well represented in PDDS-VF but not in FPW-VF, as corroborated by students' feedback in Q2. Hence, drawing from the PDDS-VF, the DElta model focuses on the progressive evolution of a project-based training path, incorporating iterative phases and divergent and convergent checkpoints. Moreover, it provides a model that can be adapted to different educational contexts. Each phase can be rescaled as needed, while modules can be simplified or expanded according to the ILOs.

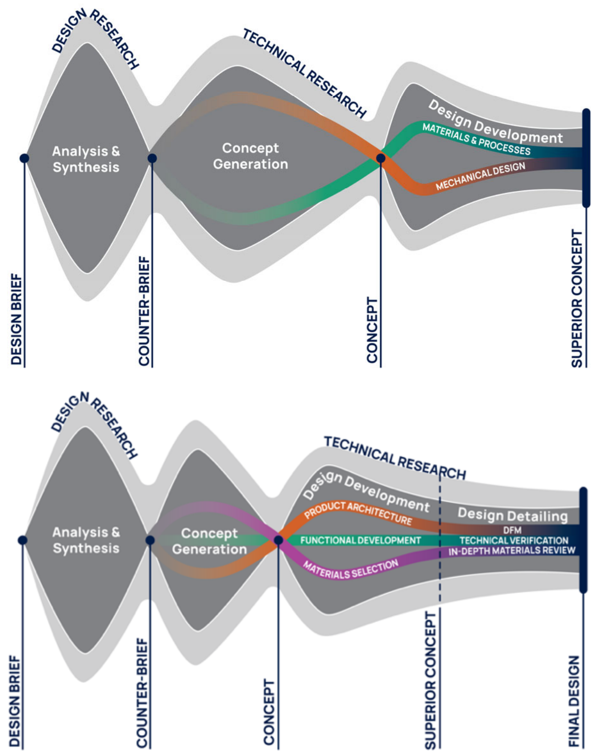

Figure 6. DElta Model for PDDS (top) and FPW (bottom) within the same timescale

5 CONCLUSION AND FUTURE WORK

The DElta model offers a formalised representation of design and engineering processes integration with a design-driven approach. Unlike previous frameworks, the DElta model dynamically integrates design, and engineering processes and adapts to diverse levels of complexity and learning goals, providing a more coherent and responsive structure for design engineering training. The visualisation's adaptiveness creates a space for faculty, students, researchers and practitioners to engage in a shared dialogue about the non-linear and collaborative interaction between design and engineering. Beyond its application in design engineering education, the DElta model has the potential for interdisciplinary programs, industry training and design research-led projects, as it provides a flexible structure for integrating creative and technical practices across diverse contexts. Future research on testing the effectiveness of the model and its impact on students' understanding and experience will lead to further refinements.

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