

RESEQUENCING CAD IN DESIGN EDUCATION: A CURRICULAR CRITIQUE OF 3D MODELLING METHODS IN PRODUCT DESIGN LEARNING

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ABSTRACT

The integration of Computer Aided Design (CAD) tools in product design education, where learning begins with parametric software such as SOLIDWORKS, often prioritises technical precision at the expense of creative and aesthetic sensibilities. Students who are developing proficiency with complex software frequently simplify their physical prototypes that meet technical criteria but compromise their original design intent.

This study explored how curricular sequencing can influence creative and cognitive outcomes. A digital modelling structure was developed to encourage early engagement with freeform modelling in a Product Design and Technology programme. Second-year students used Blender, a non-parametric digital sculpting tool, to explore and develop expressive CAD concepts before learning parametric CAD techniques in third year to support seamless cognitive progression from creative form exploration to design refinements and manufacturability, allowing students to build technical fluency on a foundation of creative expression.

Comparative analysis focused on the extent to which students' final parametric models reflect their original design intent. Evaluation criteria included aesthetic surface fidelity and accuracy of human factors proportions, supported by student reflections.

Findings suggest that beginning with Blender fosters greater creative confidence and improved representational accuracy. Students demonstrated a stronger ability to retain complex form characteristics when transitioning to parametric modelling.

By introducing freeform modelling for early-stage digital exploration, followed by parametric refinement, educators can better align CAD tool use with stages of creative visualisation and analytical thinking. The revised sequence offers a transferable model for design educators seeking to balance creativity, cognition, and manufacturability within a coherent and progressive design curriculum.

Keywords: CAD education, design cognition, freeform modelling, parametric modelling, curriculum sequencing, product design pedagogy

1 INTRODUCTION

Computer-Aided Design (CAD) is firmly established as a central component of engineering and product design education as a core digital competency aligned with contemporary industrial practice [1-3]. The increasing reliance on digital modelling environments in professional workflows has reinforced the emphasis on parametric CAD education within undergraduate curricula [4]. Parametric modelling history-linked features and constraint logic influence how students generate, refine and rationalise three-dimensional form, applying design thinking [5]. Hybrid digital toolkits have been found to enhance designer-tool interaction and support more holistic design thinking in integrated studio settings [6].

While CAD is often preferred for its technical capabilities, students sometimes encounter increased cognitive load getting acquainted to parametric digital modelmaking, resulting in design simplification and reduced exploratory refinements during conceptual stage [7]. Research indicates that although digital tools can enhance technical accuracy and visualisation, creative freedom is not evenly explored, with some students reporting constraints imposed by interface logic and early commitment to parametric workflows [8, 9]. Reviews of CAD in education tend to focus on competency and skill acquisition, with less emphasis on creative impact, cognition and design intent retention [10].

Studies suggest that CAD modelling processes can improve spatial understanding and creative expression and support functional creativity when integrated thoughtfully [11, 12]. Design cognition research shows that digitally mediated environments can impose cognitive load affecting varied ideas and strategy selection in early design phases [7, 13].

Strengthening CAD education requires integrating non-CAD thinking approaches that develop spatial reasoning, perceptual skills, and form-making sensitivity in students. Studies show that iterative, hands-on modelling, whether physical or digital, enhances spatial understanding, conceptual clarity, and problem-solving in design learning. Physical modelmaking such as clay sculpting or paper prototyping remain valuable for building an embodied sense of volume and surfaces, supporting learners' transition into advanced digital surface modelling environments [14, 15]. Similarly, observational sketching, contour studies, and photographic analysis sharpen students' ability to decode form, curvature, and proportion, skills that underpin competent use of NURBS-based curve networks and continuity control in CAD workflows. Aesthetic design research further highlights that linking natural visual references to digital abstraction strengthens students' judgement and intentionality when engaging with parametric and surface-driven tools [16, 17]. When combined with reflective documentation that supports modelling strategy development and conceptual understanding, these non-CAD practices create a more holistic learning environment that enhances students' digital modelling and design capabilities [20].

Design learning theory identifies reflection as key to develop deeper design understanding, enabling articulation of rationale and iterative refinement [18-20]. Reflective interventions have shown enhanced design performance, including idea generation, problem framing, and meaningfully engaging with ambiguity during design development [21, 22]. However, rational to link CAD tool sequencing with reflective practice remain limited. This study examines whether sequencing freeform digital modelling prior to parametric CAD better supports creative exploration while bridging toward industrial and manufacturable competencies. It proposes that establishing aesthetic coherence, proportional logic and conceptual intent in a freeform environment may reduce premature simplification while later engaging constraint-driven parametric modelling. This study focuses on how CAD tool sequencing impacts creative outcomes, aesthetic fidelity and translation of user-centred, manufacturable intent under increasing technical constraint. By foregrounding structured artefact comparison with student narration, it contributes evidence toward a cognition-led CAD pedagogy for product design education. This research was approved by the Science & Engineering Research Ethics Committee (2026_01_05_S&E).

2 METHODOLOGIES

2.1 Context and Participants

The study examines two sequential 2nd and 3rd year modules designed to scaffold creative digital fluency toward industrial manufacturability. The first module, Digital Modelling & Prototyping, centres on expressive freeform development through a design-led lens. Students deconstruct an established brand to identify and articulate its signature aesthetic language, before applying those characteristics to the design of a computer peripheral (e.g., mouse, keyboard, headset, speaker) using Blender (Figure 1 - left). The project outputs prioritise surface exploration, proportion, brand coherence, and digital representation. Blender was selected as the initial modelling platform due to its mesh-based, non-parametric workflow supporting expressive form generation and iterative experimentation [23]. However, freeform modelling can result in geometry that is problematic for manufacturing or rapid prototyping [24]. Outputs are twofold: a suite of high-fidelity renders that present the product in a brand/aesthetically accurate context, and a 3D printed prototype to demonstrate geometric integrity, watertight modelling, and physical viability. The second module, Design Studio (Industry), shifts emphasis toward technical refinement and Design for Manufacturing. Students reproduce their previous concept in SOLIDWORKS using complex surface modelling, and integrate industrial constraints including wall thickness, ribs, bosses, webs, assembly logic, and injection mould optimisation. SOLIDWORKS was selected for subsequent refinement due to its parametric, constraint-based environment, widely used in industry and design education, enabling structured design for manufacture and assembly refinement [1, 25]. Along with in-class demonstrations and direct tutor support, a suite of video resources was also created to promote asynchronous learning and to ensure clarity when approaching technically complex surface modelling tasks. The final output is a suite of industry-standard engineering drawings representing a manufacturable product (Figure 1 - right). Both modules require a process book documenting development, decision-making, and structured reflection throughout.

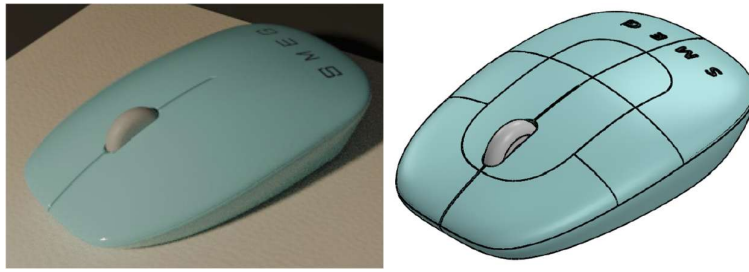


Figure 1. Computer peripheral created using freeform modelling (left) and then reproduced through parametric modelling (right)

2.2 Research Approach

This study uses a qualitative, reflective case study approach examining student artefacts, design brief adherence and narratives across two sequential modules. Early freeform outputs were compared with subsequent parametric reconstructions to assess retention of design intent under increasing technical constraints. Evaluation focused on surface fidelity, proportional accuracy, human factors resolution and integration of Design for Manufacture, Assembly and Disassembly DFMAD principles (Table 1). Artefacts, engineering drawings and prototypes were triangulated with annotated Process Books and structured reflections using a predefined assessment matrix. The matrix systematically assessed form fidelity, cognitive progression, reflective awareness and creative confidence, enabling analysis of both design outcomes and evolving decision-making processes under industrial constraint.

Table 1. Evaluation Matrix for Comparative Analysis Across CAD Modules

No.	Criterion	Module 1 output (freeform)	Module 2 output (parametric)	Submitted sources	Evaluation metric
1	Form & Aesthetic Fidelity	Surface complexity, brand coherence	Retention of curvature, dimensional accuracy	Renders, CAD models, drawings	Degree of form preservation
2	Cognitive Progression	Iterative conceptual exploration	Design refinement, constraint balance, DFMAD integration	Process books, annotated development	Creative intent and DFMAD alignment
3	Reflective Awareness	Articulation of design rationale	Explicit discussion of compromises, and technical decisions	Reflective entries, evaluations	Depth of metacognition
4	Reported Creative Confidence	Comfort with freeform modelling	Confidence in managing DFMAD constraints	Reflection excerpts, feedback	Perceived growth across modules

2.3 Data Collection

Data collection comprised two primary sources. First, designed artefacts from both modules (2 x 47 project submissions) were examined, including sketches, drawings, low-fidelity models, 3D printed prototypes, and final digital outputs. Central to each project's deliverables were students' Design Process Books, which curated project development, annotated decision-making, documented final outcomes, and embedded structured reflections throughout the design journey. Second, module evaluations were reviewed, in which students reflected on module delivery, teaching quality, learning supports, and overall sequencing, providing insight into perceived pedagogical effectiveness alongside artefact-based evidence.

3 RESULTS

3.1 Form and Aesthetic Fidelity

Students established form, proportion and surface intent in freeform modelling before translating designs into parametric environments, reducing the risk of early constraint-driven simplification (Figure 2). While not all students produced geometrically complex initial forms, several augmented their designs or selected more complex artefacts from parallel modules before transitioning to SOLIDWORKS. The requirement to produce a watertight model for 3D printing introduced geometric and topological

challenges within mesh-based workflows, yet manufacturable outputs were achieved by all students. Outputs retained complex surface qualities, demonstrated stronger alignment between early concepts and final outcomes, and showed improved handling of organic and ergonomic geometries.

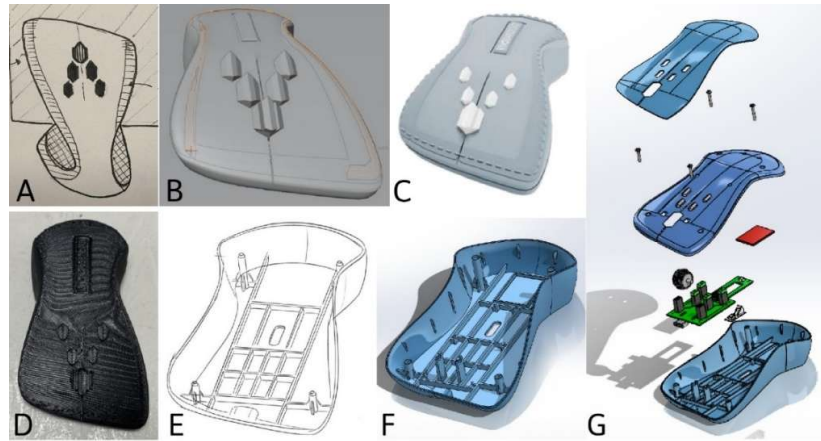


Figure 2. Workflow demonstrating how form and aesthetic fidelity were retained throughout A) initial sketch explorations, B) freeform modelling, C) digital renderings, D) 3D printing of freeform model, E) DFMA optimisation, F) parametric modelling, and G) full assembly

3.2 Cognitive Progression

Students demonstrated clear cognitive progression from exploratory form generation to structured refinement. Reflections described a shift from divergent experimentation to deliberate constraint balancing, particularly when addressing wall thickness, draft angles and assembly logic (Figure 3). Although parametric CAD was sometimes perceived as restrictive, students recognised its value in translating concepts into manufacturable outcomes. Design decisions showed stronger justification of proportion, human factor and production strategy. Final outputs aligned more closely with original intent while integrating DFMA requirements without compromising core design identity.

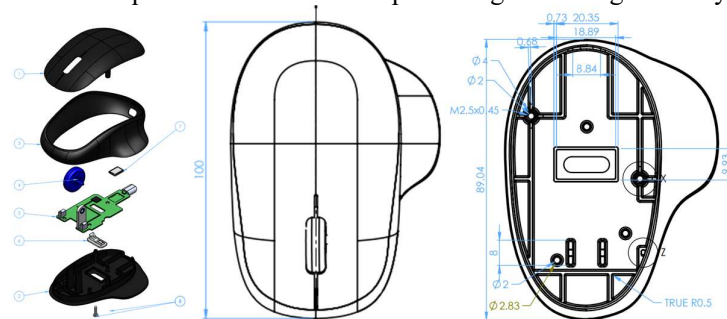


Figure 3. Students engaged with complicated surface modelling in SOLIDWORKS, implementing DFMA principles, and produced industry-aligned design documentation

3.3 Reflective Awareness and Creative Confidence

Student reflections reveal marked gains in reflective awareness and creative confidence across the sequenced modules. Students reported that Blender enabled risk-free experimentation, and how the "process of a sketch becoming a 3D product I could hold and examine... showed [them] how quick it is to learn very useful skills like Blender". One student also noted that "this is the project that [they] enjoyed the most since starting product design." Students could articulate when simplifications occurred and why, typically due to manufacturability constraints, time management pressure, linking those decisions to explicit trade-offs in their Process Books (Figure 4). Several reflections emphasised that internal geometry matters as much as external form; students reported newly appreciating wall thickness, ribs, bosses, fastening features and minimum radii as design decisions that affect both ergonomics and manufacturability, with one student noting they "learned that it's important to regularly check the minimum radius of curvature rather than waiting until the end". Accounts showed authentic learning through repeated iteration. Repeated, frustrating attempts to reconcile surface topology were reframed

as essential practice that improved technique and judgement. Parametric surface modelling was often described as more restrictive, but students also recognised its role in resolving technical detail and assembly logic, as one student stated how DFMA considerations were “*new considerations for [them] but learning them made [the student] realise how important manufacturability is in real product design*”. Time constraints limited some parametric refinements, with a few students modifying models due to deadlines. However, lecture expertise and asynchronous video resources supported technically challenging surface modelling in SOLIDWORKS. By project end, most students showed improved iteration, planning and metacognitive awareness, with greater confidence balancing creativity and manufacturable, user-centred outcomes.

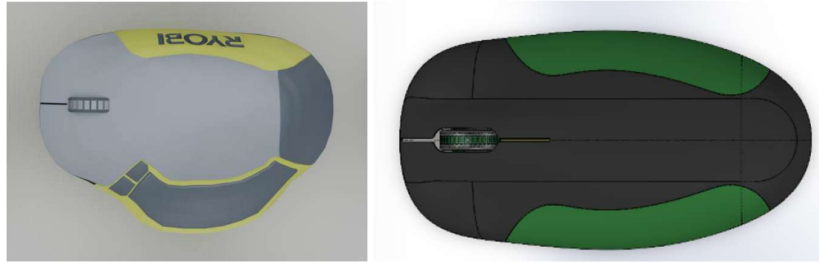


Figure 4. Example of model simplification when transitioning from freeform (left) to parametric modelling (right). Note that one half was faithfully recreated in SOLIDWORKS and then mirrored, allowing for a greater level of DFMA detailing as a result

4 DISCUSSIONS

These findings support the argument that intentional CAD sequencing strengthens industry-aligned design outcomes. Early freeform modelling enhanced divergent thinking and preserved aesthetic and proportional intent before technical constraints were applied. When parametric CAD was positioned as refinement rather than origin, students demonstrated stronger form retention and clearer articulation of design rationale. Consistent with experiential and reflective learning theory, exploratory making followed by structured constraint negotiation supported deeper cognitive development. Reflection functioned as a safeguard against software-determined decisions, reinforcing user-centred, sustainable and manufacturable intent. Pedagogically, the results advocate a shift from software-first to cognition-first sequencing. Early modules should prioritise creative exploration and surface literacy, with later modules introducing industry constraints such as manufacturability, assembly logic and sustainable DFMA. This staged progression offers a transferable framework that aligns creative integrity with industrial relevance and sustainable best practice.

5 LIMITATIONS AND FUTURE WORK

This study is the first evaluation of the revised module sequence, so there is limited longitudinal comparison. Future work will situate this sequencing model in a programme-level context to evaluate broader pedagogical impact, while also considering how it impacts traditional sketching capabilities.

6 CONCLUSIONS

This study shows that introducing freeform digital modelling early supports creative exploration and representational accuracy. Establishing form, proportion and intent before applying parametric constraints enabled stronger retention of design intent during technical development. Creativity was not reduced by later industrial requirements, though targeted refinements were needed for manufacture. Structured reflection improved articulation of rationale, awareness of compromise and avoidance of tool-driven limitation, strengthening communication of user-centred and manufacturable outcomes. The findings emphasise selecting CAD tools based on pedagogical alignment as well as industry relevance. The proposed sequencing model offers a transferable framework for balancing creative integrity with DFMA implementation in product design curricula.

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