Material Play: A Flashcard-Based Pedagogical Toolkit for Entangled Material Learning in Undergraduate Product Design.

First name/s Last name/s[a]

[a]Affiliation name: X

*Corresponding author e-mail: X

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Abstract: This paper presents the Material Ideation Toolkit, a flashcard-based pedagogical intervention that embeds playful material exploration in undergraduate product design education. Traditional approaches privilege technical analysis, overlooking the affective and experiential dimensions of material engagement. Grounded in constructivist pedagogy and material-driven ideation, the toolkit enables students to engage in exploratory, reflective "material play," treating materials as active collaborators in design. Within first-year studio projects, the cards prompt curiosity and dialogue, helping students negotiate both functional and experiential properties. This embodied, entangled interaction reveals how playful engagement with matter can deepen material literacy and creative confidence. The paper contributes a framework for entangled material learning, positioning play as a vital mode of inquiry through which designers co-create understanding with materials, bridging technical competence, sensory awareness, and imaginative exploration. The study is based on qualitative observation of classroom interactions during a first-year design studio.

Keywords: Material Play; Constructivist Pedagogy; Entangled Material Learning; Material-Driven Ideation.

1. Introduction

Materials play a central role in product design practice, shaping not only a product's technical performance but also its experiential, affective, and atmospheric qualities, which influence how it is perceived and used. As Ashby and Johnson (2014) note, materials hold "overlapping roles": they enable function while simultaneously carrying emotional resonance, aesthetic presence, and experiential character. Teaching this duality is particularly challenging in early undergraduate design education. First-year students often encounter materials through scientific and technical framings, properties, classifications, and processes presented in an abstract manner. However, they frequently struggle to translate

this knowledge into studio practice, where materials must be understood in terms of how they feel, behave, signal meaning, age over time, or provoke new directions in ideation.

Existing resources in design curricula tend to reinforce this imbalance. Technical compilations, such as Thompson's (2017) Materials Sourcebook for Design Professionals, provide invaluable information for performance-based selection but offer limited support for treating materials as creative catalysts or sensory prompts in early ideation. Meanwhile, material-driven pedagogies, including Material Tinkering (Parisi et al., 2017) and meaning-driven material selection (Karana et al., 2010), foreground sensorial inquiry, experimentation, and encounter. These approaches view materials as collaborators in design, yet they often depend on specialist facilities, extended workshop access, or more advanced students who have already developed material fluency. As a result, fewer lightweight, repeatable interventions exist to help first-year students think with materials, through touch, comparison, dialogue, and reflection, rather than only about them.

Within the broader discourse of play design, materials are increasingly understood not as passive substrates but as active agents that provoke, resist, and shape creative exploration (Gudiksen & Skovbjerg, 2020; Poulsen, 2022). Play, in this context, functions as a generative framing device, inviting suspension of habitual constraints, openness to ambiguity, and engagement with matter in exploratory, low-risk ways. This relational view of materials aligns closely with contemporary design pedagogies that emphasise entanglement, emergence, and material agency.

This paper responds to these challenges and opportunities by presenting and critically examining the Material Ideation Toolkit, a set of physical flashcards designed to introduce playful, sensory material exploration into a first-year product design studio. The toolkit integrates functional and experiential dimensions of materials in a simple, accessible format that supports ideation within problem-based learning environments. Grounded in constructivist theories of learning, which emphasise meaning-making through active engagement (Bruner, 1990; Brown & King, 2000), and in project-based approaches that structure learning through applied inquiry (Bell, 2010), the toolkit aims to develop both material knowledge and creative confidence.

The study is guided by two research questions: RQ1: How can structured, tactile prompts (flashcards) support first-year design students in engaging materials as more than technical constraints? And, RQ2: In what ways does this toolkit activate constructivist, problem-based, and reflective learning within the design studio?

The paper contributes: (i) a replicable studio intervention that operationalises material play for early-stage learners, and (ii) an articulation of how materials, students, and studio problems become entangled through this practice, enriching material literacy and revealing material agency in beginner-level design contexts.

The paper is structured as follows: Section 2 reviews the literature on material pedagogy, play-material engagement, and card-based design tools. Section 3 describes the development of the flashcards and their integration into studio teaching. Section 4 presents

findings from their deployment in a first-year design project. Section 5 concludes with implications for material education and directions for future research.

2. Background & Theoretical Context

2.1 Material Education in Product Design

Material education in product design has expanded considerably beyond the traditional concern with selecting the "right" polymer, metal, or composite for a product's technical requirements. While a functional understanding remains foundational, it no longer captures the complete set of responsibilities designers assume when engaging with materials. Ashby and Johnson's (2014) notion of materials' "overlapping roles" foregrounds this complexity: materials are simultaneously technical systems and carriers of aesthetic, emotional, and atmospheric qualities that shape user experience. This duality poses a key pedagogical challenge. First-year students must learn to recognise how materials behave and perform while also understanding how they communicate meaning, evoke affect, and participate in the creation of product character.

Recent pedagogical work positions materials as active catalysts for ideation rather than neutral substrates. Approaches such as Material Tinkering (Parisi et al., 2017) and meaning-driven material selection (Karana et al., 2010) encourage students to explore sensory characteristics, experiment with unfamiliar substances, and investigate how texture, colour, transformation, and degradation open new creative avenues. In these models, material inquiry is not a secondary step; it is a design method in itself. Encounter, manipulation, and interpretation reveal qualities that would remain invisible in purely analytical or specification-driven approaches. This resonates strongly with broader play-design perspectives, in which materials act as provocateurs, shaping and reshaping the designer's imagination (Gudiksen & Skovbjerg, 2020; Poulsen, 2022).

However, much of the existing literature describes approaches that rely on well-equipped workshops, extended studio access, or students who already possess material confidence. Less attention has been given to lightweight, repeatable, classroom-friendly interventions that support early-stage learners in navigating both functional and experiential dimensions of materials. First-year students often need tangible, accessible tools that make material qualities visible, discussable, and active within rapid ideation cycles. This gap underpins the motivation for the Material Ideation Toolkit.

2.2 Constructivism, Problem-Based Learning, and Meaning-Making

Constructivist theories provide a pedagogical foundation for understanding why tactile, exploratory encounters with materials support deeper learning. Constructivism positions students as active makers of meaning, interpreting new concepts through experience, interaction, and reflection rather than passively receiving information (Bruner, 1990). Brown and King (2000) emphasise the importance of sensory input within this learning process. Physical stimuli help students test assumptions, confront contradictions, and build conceptual understanding.

These principles align naturally with design education. Studio environments rely on problem-based learning in which students respond to open-ended briefs, cycling between research, ideation, prototyping, and critique. Bell (2010) argues that such environments enhance motivation and retention because knowledge is used immediately within a situated, purposeful context rather than taught in abstraction.

In the context of materials, constructivist learning implies that students must go beyond remembering material properties. Bloom's Taxonomy (O'Neill & Murphy, 2010) highlights that genuine material literacy requires higher-order cognitive skills: applying, analysing, evaluating, and creating. The Material Ideation Toolkit is intentionally designed to scaffold this ascent. By offering a physical artefact that sits between theoretical instruction and studio practice, the toolkit enables students to interrogate materials, compare alternatives, evaluate trade-offs, and integrate material insight into iterative design decisions. The cards thus function as mediators between knowledge and action, supporting novice designers as they construct understanding through doing, sensing, and discussing.

2.3 Play, Entanglement, and Material Agency

In this study, play is understood not as entertainment or leisure but as a mode of exploratory, low-risk engagement that opens space for curiosity, speculation, and emergent possibility. In line with Parisi et al. (2017), play describes an embodied, improvisational form of inquiry where materials are probed for what they can do, how they behave, how they resist, and how they might transform. Play suspends premature judgement, allowing students to examine materials through an affective and sensory lens—attending to patina, texture, temperature, failure modes, and atmospheric qualities. This resonates with play-design scholarship that frames play as an exploratory stance toward matter, characterised by openness, friction, and imagination (Gudiksen & Skovbjerg, 2020; Poulsen, 2022).

The notion of entanglement further extends this relational view of material engagement. Entanglement describes the reciprocal, co-evolving relationships between student, brief, and material. As students ask questions such as "Will acrylic snap?", "Will steel rust outdoors?", or "Could ageing become a desired feature?", they negotiate between intention and material behaviour. Materials "push back," resist certain forms, invite others, and subtly redirect design trajectories. This echoes contemporary perspectives in material-centred design and material methods research, where materials are understood as active participants in inquiry rather than passive carriers of properties (Woodward, 2020; Ravnløkke & Binder, 2023).

The Material Ideation Toolkit is designed to mediate this entanglement. Each flashcard offers sensory cues (appearance, tactility) alongside conceptual prompts (properties, processes, applications), enabling materials to "speak" within the studio conversation. As students manipulate and discuss the cards, materials exert agency, shifting perspectives, reframing constraints, or suggesting new directions. In this sense, the toolkit supports a form of dialogic material play in which meaning emerges through interaction, negotiation, and shared exploration. It operationalises material agency in a lightweight, accessible way suited

to early learners, grounding relational, affective, and emergent modes of material engagement in everyday studio practice.

In this sense, the toolkit supports a form of making-adjacent material inquiry: even without fabrication, students 'make sense' of materials through combinatory gestures, arrangement, and manipulation, treating ideation itself as a form of pre-material making.

2.4 Card-Based Design Toolkits in Design Education

Card-based toolkits have an established history in design research as mediating artefacts that structure collaboration, support ideation, and scaffold exploratory thinking. Halskov and Dalsgård's (2006) Inspiration Card Workshops show how domain and technology cards can be combined to facilitate collaborative concept generation, illustrating the artefact-mediated emergence of ideas in co-design settings. Lucero and Arrasvuori's (2010) PLEX Cards present cards as a framework for playful experiences and as a way to inspire designers when generating playful concepts. Building on these and related techniques, Lucero et al. (2016) argue that design cards operate as tangible idea containers that support combinatorial creativity and enable collaboration in creative design processes.

Roy and Warren's (2019) review of 155 card-based design tools further demonstrates the versatility of card decks in professional and educational contexts, noting that cards can stimulate creativity, trigger associations, and serve as flexible reference tools, while their effectiveness depends on carefully considered graphic and informational design. Rather than introducing a wholly new format, the Material Ideation Toolkit builds on this lineage by focusing the card content explicitly on materials and their overlapping functional and experiential roles.

By presenting both technical properties and experiential cues, the flashcards adapt the affordances of card-based methodologies to support playful, material-centred inquiry in early design education. Flashcards are well-suited to first-year learners because they reduce cognitive load, foreground visible choices, and externalise knowledge in a manipulable form (Lucero, 2012; Roy & Warren, 2019).

3. Toolkit Design and Methodology

3.1 Toolkit Description

The Material Ideation Toolkit comprises a set of physical flashcards designed to support early-stage, playful material exploration in undergraduate product design education. Each card presents a single material and provides concise information intended to prompt both technical analysis and experiential, affective interpretation. The cards follow a consistent structure that includes:

- Material overview: common names, variants, and general descriptions.
- Key functional characteristics: strength, hardness, flexibility, durability, thermal behaviour, and other performance considerations.

- Environmental and chemical constraints: recyclability, degradation patterns, moisture and UV resistance, and sustainability factors.
- Manufacturing considerations: typical forming processes, constraints, and implications for geometry and finish.
- Typical applications: familiar product examples that situate the material within everyday design contexts.

The physicality of the cards is central to their pedagogical intention. Printed at a handheld scale, they are designed to be arranged, compared, stacked, clustered, and placed at the centre of conversation. Their tactility invites material encounter, gesturing, touching, pointing, and reorganising, actions that bring material qualities to the foreground. This material engagement supports the kinds of sensorial, atmospheric, and affective interpretations emphasised in contemporary play-material scholarship (Gudiksen & Skovbjerg, 2020; Ravnløkke & Binder, 2023).

The toolkit was intentionally created with a twofold pedagogical purpose: (1) Design for function: enabling students to reason about feasibility, strength, manufacturability, and environmental impact. And: (2) Design for experience: prompting considerations of sensory feel, emotional resonance, surface character, ageing, and meaning-making.

In the first-year studio, the cards were introduced during the ideation phase of a rapid, problem-based brief (for example, designing a coat hook – See Figure 3 for student example). Students used the cards to interrogate material decisions, explore alternatives, and spark discussion. Rather than functioning as static reference sheets, the cards were treated as material provocations, objects that helped shift conversation, reframe assumptions, and introduce unexpected possibilities.

Figure 1 presents an example of a material flashcard, illustrating the visual and informational layout used throughout the toolkit. Figure 2 shows examples of rendered materials that supported students during early sketching and ideation. Figure 3 presents student work from the coat-hook project, demonstrating how the flashcards prompted deeper exploration of materiality and enabled the development of more refined, materially informed minimal designs.

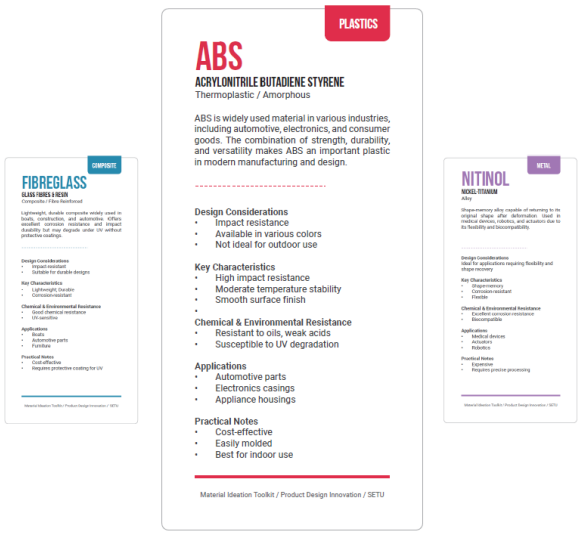

Figure 1 - Material Flashcards: Each material category (polymer, metal, and composite) is colour-coded for clarity. The core content of each card includes a material overview, key design considerations, functional characteristics, chemical and environmental factors, typical design applications, and practical notes for use in early-stage ideation.

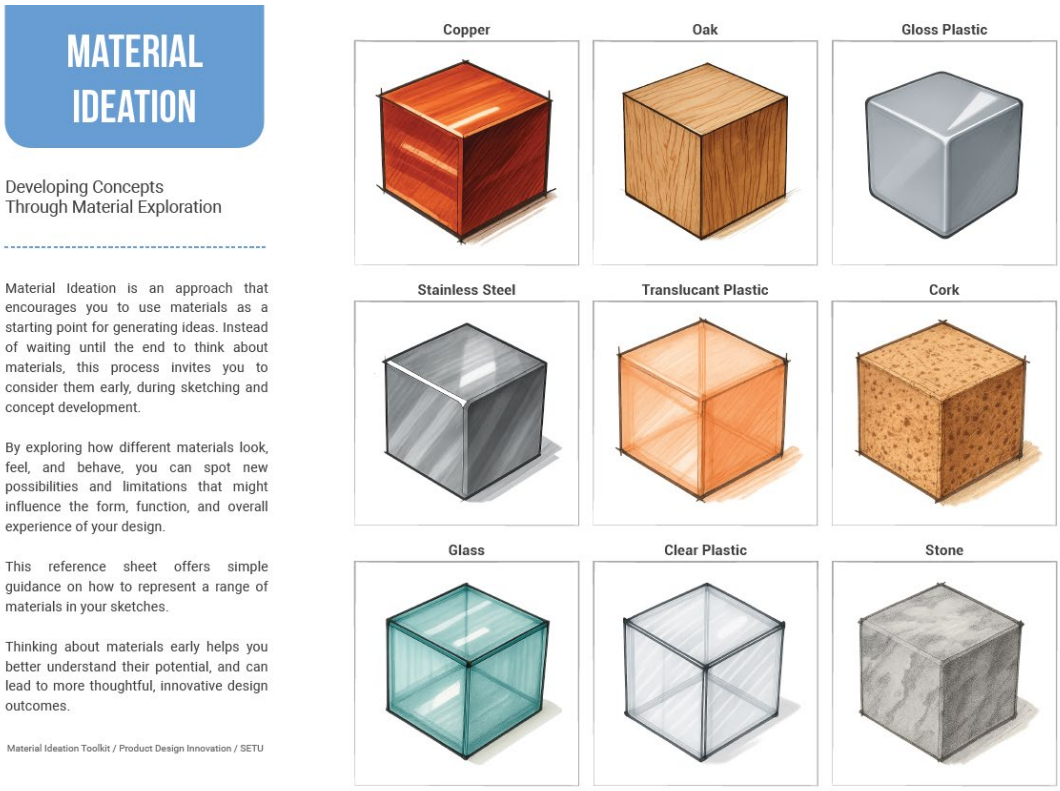

Figure 2 - Material Rendering Flashcard: This card presents marker-rendering techniques in a single swatch, providing students with a reference for depicting material qualities during ideation. Its primary purpose is to support students in exploring and communicating material characteristics within their Sketchwork while they continue to develop their rendering and drawing skills.

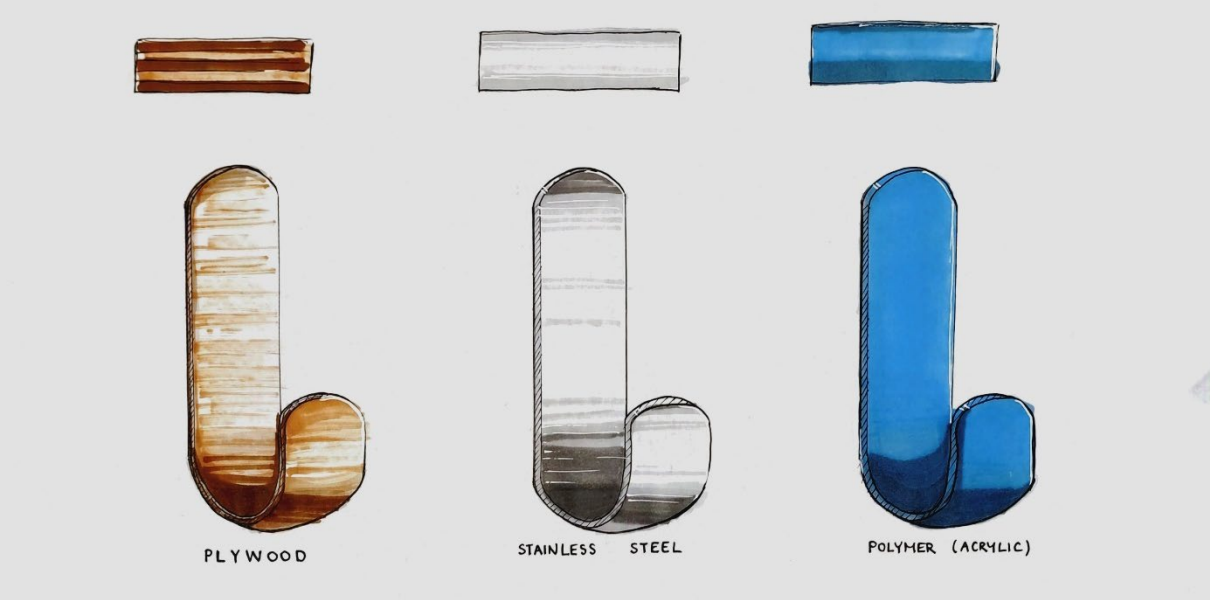

Figure 3 - Student Example: Coat hook concepts exploring material alternatives through Sketchwork, with material qualities rendered to support visual and functional evaluation.

3.2 Pedagogical Deployment

This subsection describes the toolkit's components and pedagogical logic. Its evaluative outcomes are discussed in Section 4.

The deployment took place in a first-year undergraduate product design studio within a project-based learning environment, where students responded to an open-ended design brief. This learning context emphasised problem-based inquiry, requiring students to integrate theoretical material knowledge with iterative exploration, peer dialogue, and hands-on reasoning.

Activity Structure: The flashcards were introduced at the ideation stage and used throughout group and individual design work. Students were invited to engage playfully and experimentally with the cards, using them as prompts to:

- Compare and critique materials based on both functional performance and experiential or affective qualities.
- Interrogate feasibility (e.g., brittleness, load, forming processes) and environmental implications.
- Generate and refine ideas, using material cues to provoke alternative directions.
- Articulate reasoning aloud, creating shared moments of negotiation among peers.

The cards did not prescribe "right answers." Instead, they facilitated open-ended, emergent conversation, mirroring the exploratory stance toward matter emphasised in play design research. Drawing on Poulsen (2022), the activity cultivated playfulness as a cognitive and emotional disposition, enabling students to hold ambiguity, test multiple possibilities, and remain open to reframing assumptions embedded in their early design sketches.
These interactions transformed the cards into mediating objects, devices through which students negotiated tensions between design intent, material behaviour, and project constraints. This aligns with contemporary discussions in material-led play design, where artefacts catalyse entanglement between human actors and material agents.

Data and Observational Method: The analysis in this paper draws on multiple forms of qualitative observation:

- Classroom observations of student discussion, gestures, and collaborative decision-making during regular teaching activity.
- Examples of material-related questioning, such as "Will this crack if dropped?" or "How will it weather outdoors?", illustrate analytical and reflective reasoning.
- Informal student feedback, noting that the toolkit provided "structure," "a starting point," and "a physical thing to think with."
- Reflections on engagement, including increased willingness to compare alternatives, articulate trade-offs, and justify choices during critiques.

Ethical Considerations: All observations were drawn from routine classroom activity. No personal data was collected, no student work is identifiable, and no comments are attributed to specific individuals. The study complies with ethical norms for pedagogical research within higher education.

4. Findings and Discussion

4.1 Finding 1: The toolkit stimulated "material play"

Across the studio sessions, students consistently used the flashcards to engage in speculative, exploratory, and playful "what if" conversations about materials. Rather than selecting a material solely to satisfy functional criteria, students probed how materials might behave, feel, change, or fail. They discussed patina ("Would this age in an interesting way?"), surface temperature ("This feels too cold for a household context"), environmental exposure ("Will this degrade outdoors?"), and forming constraints ("Can this geometry be moulded?").

These behaviours align with the definition of material play articulated earlier: an exploratory, low-risk mode of inquiry in which students probe what materials can do, how they resist or enable specific directions, and what possibilities they introduce. The discussions were improvisational and emergent; students shifted direction mid-sentence, combined materials unexpectedly, or reconsidered their concepts in response to sensory or speculative cues. This resonates strongly with play-based approaches in design research, where playful attitudes generate new relations between people and matter (Gudiksen & Skovbjerg, 2020; Poulsen, 2022).

Although the studio lacked laboratory facilities for hands-on tinkering, the flashcards acted as a lightweight analogue for Material Tinkering (Parisi et al., 2017). Students used the cards to enact a form of conceptual experimentation: manipulating, juxtaposing, and testing materials in dialogue rather than in the physical workshop. This demonstrates how structured prompts can activate the sensorial, affective, and imaginative dimensions of material inquiry even in resource-limited educational contexts.

Interpretation (RQ1): The evidence shows that the toolkit successfully helped students treat materials as generative, creative provocations rather than as post hoc justifications for preformed ideas. In doing so, it supported students in expanding imagination, questioning assumptions, and exploring alternative trajectories, clear markers of material play and experiential reasoning.

While the cards successfully supported conceptual material play, they remain representational rather than fully embodied material encounters; future work may benefit from integrating the toolkit with physical samples to deepen sensorial engagement.

4.2 Finding 2: The Toolkit Functioned as an Entanglement Device

During the studio project, the flashcards frequently occupied the centre of both physical and conversational interaction. Students placed them on the table, gestured to them, rearranged them, and used them to mediate negotiation between brief, concept, and material. This positioned the cards as material-discursive anchors, enabling the formation of a triadic relationship between student, project, and matter.

For example, students observed that “acrylic will snap if too thin,” prompting a reconsideration of geometry. In another group, a student reframed weathering as an aesthetic asset rather than a technical flaw (“bronze could age beautifully outdoors”). These moments illustrate material agency: the material, represented through the card, asserted influence, reshaped intentions, or shifted the conceptual direction of the design. This is characteristic of entanglement, as described in Section 2, in which materials and designers co-constitute one another through iterative exchanges (Ravnløkke & Binder, 2023; Woodward, 2020).

Pedagogically, these interactions support constructivist theories of meaning-making (Bruner, 1990). Knowledge emerged not through transmission but through situated negotiation, where students responded to materials’ constraints, potentials, and resistances. The flashcards helped make these qualities visible and discussable, enabling students to reason through materials in action.

These observations also align with Schön’s (1983) reflection-in-action. Students thought with and through materials while designing, engaging in real-time adjustments as materials “talked back.” This reflexive interplay demonstrates why material entanglement is both a cognitive and embodied dimension of studio learning.

Interpretation (RQ2): In practice, the toolkit served as a designed mediator of entanglement. It foregrounded material presence, facilitated reflection-in-action, and invited students to treat materials as co-creative agents rather than static inputs. This contributes evidence that structured prompts can meaningfully activate situated, dialogic, and material-led learning in early design education.

4.3 Finding 3: The Toolkit Supported Higher-Order Learning Behaviours Early

Student interactions mapped clearly onto the upper levels of Bloom’s Taxonomy, indicating that the toolkit supported progression beyond introductory knowledge recall (O’Neill & Murphy, 2010):

- Remember / Understand: identifying materials and recalling baseline traits (“ABS is impact resistant”).
- Apply: matching materials to functional demands (“This thickness will not support weight”).
- Analyse: interrogating constraints such as brittleness, manufacturability, weathering, cost, or safety.
- Evaluate: weighing trade-offs between sustainability, durability, aesthetic effect, and feasibility.
- Create: generating material-led ideas, such as incorporating ageing as a feature or using texture intentionally.

The appearance of creative-level reasoning is particularly notable in an early-stage cohort, where material choices are often superficial or post-rationalised. The flashcards appear to scaffold movement between abstraction and application, enabling students to externalise

and compare reasoning in shared dialogue, aligning with constructivist scaffolding principles (Brown & King, 2000). Students used the cards to test assumptions, justify decisions, and articulate material rationale during critique.
While these findings are encouraging, they reflect an early-stage intervention rather than longitudinal evidence. Future research could explore whether continued use of such tools strengthens material reasoning across subsequent projects or semesters.

4.4 Interpretations & Limitations

Taken together, this finding suggests that the toolkit functions as a bridge between theoretical material knowledge and situated design action. Supporting higher-order reasoning early contributes to the development of material literacy, enabling students to move fluidly among the functional, experiential, and expressive dimensions of materials.

The findings presented here reflect a single deployment within a first-year cohort and are primarily based on qualitative observations. The study does not claim generalisability beyond this context, nor does it include longitudinal assessment of how material reasoning develops over time. Further research across multiple cohorts and studio settings would strengthen the understanding of the toolkit's broader pedagogical impact.

5. Conclusion and Future Work

This paper addressed a persistent challenge in early design education. Although first-year students are introduced to materials primarily through technical and theoretical instruction, they are also expected to apply their knowledge creatively and confidently in studio projects. Existing resources strongly support performance-based material selection, yet far fewer pedagogical tools enable novice designers to encounter materials as experiential, sensorial, affective, and meaning-bearing collaborators during ideation.

To address this gap, the paper introduced the Material Ideation Toolkit, a set of physical flashcards designed to embed material play into a first-year product design studio. The toolkit integrates functional and experiential dimensions of material knowledge, providing tactile prompts that bridge abstract theory and situated design action. Through qualitative classroom observations, the study explored how the toolkit operated within a real teaching environment.

Three key findings emerged.

- First, the toolkit stimulated material play, prompting students to explore speculative possibilities, consider sensory and behavioural qualities, and engage in lightweight forms of experimentation. These interactions activated curiosity, improvisation, and emergent reasoning, hallmarks of playful engagement with matter.

- Second, the toolkit acted as an entanglement device, mediating the relational space between student, brief, and material. The cards enabled reciprocal negotiation, where materials, through their described behaviours, "spoke back" and reshaped

intention. This dynamic reflects constructivist meaning-making and aligns with contemporary perspectives on material agency and relational design practice.

- Third, the toolkit supported higher-order learning behaviours atypical for early-stage learners. Student activities mapped onto analysis, evaluation, and creation within Bloom's Taxonomy, demonstrating that structured material prompts can scaffold the transition from remembering properties to designing with material behaviours in mind.

The study contributes to design education in two main ways:

1. A replicable studio intervention that operationalises material play for first-year design students without requiring specialist facilities, extensive workshop time, or advanced skill levels.

2. An articulation of how physical prompt systems, such as flashcards, can mediate entangled relationships between learner, context, and material, supporting reflective, situated, and relational forms of material reasoning.

Several avenues for future research emerge from this study. The toolkit could be expanded with complementary card sets, for example, manufacturing process cards, sustainability and lifecycle cards, or cards integrated with digital material scanner outputs. A longitudinal study spanning multiple semesters could reveal whether early gains in material literacy have lasting effects on students' confidence and sophistication in later design projects. Further research is also needed to define and assess "confidence with materials" as a measurable learning outcome within design pedagogy.

Contemporary design practice increasingly demands graduates who can navigate the interplay of performance, sustainability, affect, mood, meaning, and user experience, all dimensions shaped through material choice and material behaviour. Developing this literacy early, through playful and entangled engagement with materials, strengthens students' creative capacity and better prepares them for the relational, emergent, and materially situated realities of professional design practice.

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About the Authors:

Author 1 add an author bio that describes research interests and any other achievements in a maximum of 40 words. This description is 21 words. [Leave blank for initial submission] [X Author Bio]

For Reviewer: Acknowledgement of AI Use

Generative AI tools were used in limited and fully supervised ways during the preparation of this paper. Grammarly was employed to support spelling, grammar checking, and improvements to the clarity of English expression. ChatGPT was used to assist with structuring the paper, refining academic phrasing, and interrogating sections of writing for coherence and clarity. All research, analysis, theoretical framing, toolkit design, data collection, and conclusions are entirely my own work. The Material Ideation Toolkit, including the design and creation of the flashcards, is solely authored by me. AI tools were not used to generate research findings, conduct analysis, produce results, or write substantive academic arguments. Human oversight was maintained throughout the writing process, and full responsibility for the content, interpretations, and conclusions presented in this paper remains with the author.