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Investigating the role of embedded tactile and sensory technology as a digital disruption in technology-integrated design education

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Abstract

This study investigates the integration of Embedded Tactile and Sensory Technologies as digital disruptions in South African design education, exploring how additive manufacturing and tactile interfaces can bridge theory with experiential learning. Grounded in Experiential Learning Theory (ELT), a Design-Based Research (DBR) methodology was employed to develop and test an educational intervention at a South African University of Technology. The research examined how the embedded technologies enhance student engagement, inclusivity, and creative problem-solving within a context of limited resources. Findings indicate that while the embedded technologies offer significant pedagogical affordances, their widespread adoption is hindered by implementation costs, lack of curriculum integration, and educator training gaps. This paper contributes empirical insights into these challenges and presents a practical, evidence-based framework for embedding tactile learning into design curricula, advocating for technology-enhanced environments that foster digital literacy and hands-on design skills.

Keywords: Embedded tactile and sensory technology, design-based research, experiential learning, digital disruptions

Introduction

In the 4IR, higher education institutions are pressed to adopt innovative pedagogies that improve digital literacy and problem-solving. integration of Embedded Tactile and Sensory Technologies (ETaSTs) as, particularly 3D-Printing, offer a means to bridge theory and practice through experiential learning. This study investigates ETaSTs as digital disruptions in design education, examining their role in connecting theoretical concepts with practical engagement. Despite their potential, these technologies are not widely integrated into formal curricula, especially in under-resourced, non-STEM fields. This paper explores the pedagogical affordances and limitations of ETaSTs through a DBR methodology at a South African university of technology.

Literature review

Key terminology

For clarity, key terms are defined as follows. Embedded Tactile and Sensory Technologies (ETaSTs) are technologies integrated into the curriculum to provide tactile and sensory experiences, primarily through 3D-Printing in this study. Embedded signifies seamless integration within existing learning activities, rather than standalone or supplementary tools. Tactile refers to learning through touch, while Sensory encompasses a broader range of senses for a multi-modal experience. Tactile **Visualisation** is the use of physical models to represent abstract concepts, understood through touch and sight.

Preliminary literature review

The integration of Embedded Tactile and Sensory Technologies (ETaSTs), in the form of 3D-Printing, has gathered increasing attention in education due to its potential to support experiential, multisensory, and inclusive learning (Blikstein 2013). Kolb (1984), in Devi and Thendral (2023), denotes that Experiential Learning Theory (ELT) provides a robust theoretical lens for understanding the pedagogical value of ETaSTs. Through concrete experiences, reflective observation, abstract conceptualisation, and active experimentation, learners can engage deeply with subject matter, particularly when abstract concepts are made tangible through tactile tools.

Research has shown that 3D-Printing fosters spatial reasoning, motivation, and interdisciplinary collaboration (Fokides & Lagopati 2024; Trujillo-Cayado *et al.* 2024). Staněk (2021) reinforces these findings, highlighting 3D-Printing's role in promoting creativity, technical skills, and hands-on engagement. Hollmann, Junger and Notni (2025) investigated 3D-Printing for creating multisensory materials and highlighted its potential in professional learning environments, despite technical limitations. Kaplan and Pyayt (2024) argued that 3D-Printed tactile visualisations improve data representation and help bridge digital tools with hands-on engagement. Tactile visualisation, in this context, refers to the use of physical objects to represent data or concepts, which can be understood through both touch and sight, and can also engage the imagination. Varano and Zanella (2023) advocated for multimodal, redundant design to avoid misconceptions in scientific data interpretation, supporting Universal Design for Learning principles.

The use of 3D-Printing in tactile content creation has been extensively explored in relation to visually impaired learners. Studies by Barros, Correia and Teixeira (2023) and Gual Ortí, Amat Cozar, Puyuelo Cazorla and Lloveras Macia (2024) emphasise the value of printed models for accessibility and inclusion. Volumetric symbols and tactile maps, as evaluated by Voženílek, Kozáková, Štávová, Ludíková, Růžičková, and Finková (2015), demonstrated high levels of recognition, suggesting that 3D-Printing can effectively replace or augment traditional 2D materials. Enhancing such learning methods further, Nagassa, Pham, Butler, Holloway, Stefanov, de Vent, and Marriott (2025) developed co-designed, audio-supported models to facilitate tactile assembly for blind learners.

South African higher education has shown growing interest; it faces significant implementation challenges. Inoma, Ibhadode and Ibhadode (2020) and Mashwama and Madubela (2025) noted the digital divide, inconsistent policy frameworks, and limited infrastructure as major barriers. Schelly, Anzalone, Wijnen and Pearce (2019) similarly emphasised that open-source 3D-printing technologies can mitigate such barriers by enabling low-cost, scalable access to additive manufacturing tools, thereby supporting inclusive, practice-based learning in under-resourced contexts. However, initiatives such as the Idea2Product (I2P) Lab provide a promising example of applied 3D-Printing in design education (Alabi, de Beer, Wichers, & Kloppers 2020). Dias, Soares, Guimarães, Martínez, Luz, and Lima (2024) further show how 3D-Printing enables custom assistive devices in inclusive classrooms, highlighting its empowerment potential. Custom assistive devices are defined as objects or tools created to meet the specific needs of an individual, often to assist with a disability or to enhance learning.

In addition, the literature also reflects on practical constraints. Teachers face difficulties with print times, model validation, and skill gaps (PrintLab 2023). Blogs by Babinszki (2025) underscore the growing but uneven application of 3D-Printing for blind learners. Stone, Kay, Reynolds, and Brown (2020) explored the benefits of combining 3D-Printing with service learning to produce accessible educational materials, enhancing engagement for all participants.

Recent developments in tactile sensory systems (Xi, Yang, Li, Wei, Zhang, Dong, Yang, Sun, & Hua 2024) suggest that 3D-Printing may soon be integrated with responsive, stretchable materials to build truly interactive learning aids. Kumar, Chen and Ren (2019) documented advances in printable sensors for robotics and wearables, highlighting future opportunities in educational settings.

Design-Based Research (DBR) offers a practical framework to harness these benefits. Reeves (2006), in Kim and Park (2023) and Narayan, Herrington and Cochrane (2019), emphasise DBR's capacity for iterative development in complex educational environments. It enables the design of the intervention, testing, and refinement of interventions in real-world settings, while contributing to theory.

In conclusion, while the potential of ETaSTs in education seems well-supported, realising its efficacy depends on addressing access gaps, aligning with pedagogy, and institutional investment. This study builds on these insights with empirical data from a South African University of Technology, using DBR to evaluate a tactile 3D-Printing intervention grounded in experiential learning.

Post-intervention literature review (extended comparator)

The post-intervention literature review process began with the identification of 650 studies from various databases, including Web of Science (n=180), Scopus (n=325), and Elsevier (n=136), with nine from unspecified sources. After removing 332 duplicate references, 318 studies were screened. Of these, 110 irrelevant studies were excluded, leaving 208 studies for retrieval. All 208 studies were successfully retrieved and assessed for eligibility. During this assessment, 91 studies were identified for key themes and frequency analysis, and 117 for affordances. A total of 183 studies were subsequently excluded based on specific criteria: 73 for wrong outcomes, 35 for wrong comparator, 57 for wrong intervention, and 18 for wrong study design. Ultimately, 25 studies were included in the final review (Figure 1).

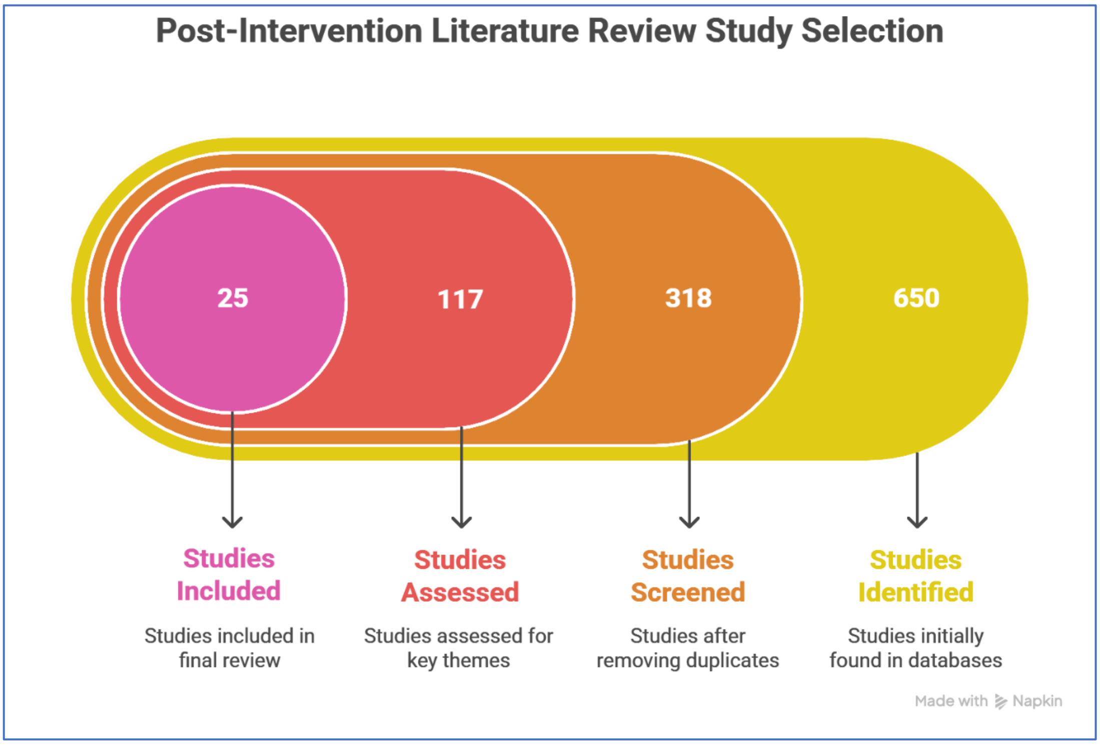

Figure 8: Selection diagram illustrating the elimination process of references

The post-intervention literature strongly reinforced the pedagogical potential of Embedded Tactile and Sensory Technologies (ETaSTs), especially 3D-Printing, in promoting experiential and inclusive learning. Across global and local contexts, these technologies have shown considerable value in supporting students' cognitive engagement, particularly for those who learn best through hands-on and visual-tactile interactions (Kaplan & Pyayt 2024; Trujillo-Cayado *et al.* 2024).

The findings from this study support existing research that highlights the role of 3D-Printing in improving spatial reasoning and enhancing motivation (Kolb 1984, cited in Kim & Park 2023; Fokides & Lagopati 2024). Learners involved in the South African University of Technology intervention reported that tactile design tasks helped them grasp theoretical concepts more concretely. These responses align with the principles of Experiential Learning Theory (ELT), particularly the cycle of reflection and application enabled through active material engagement.

Moreover, the literature supports the use of 3D-Printing as a transformative tool for accessibility. Several studies (Barros *et al.* 2023; Kolitsky 2014; Hollingsworth & Petersen 2017) underline the importance of tactile representation in making abstract concepts and spatial information more inclusive. Our data reflected similar benefits, with tactile artefacts enabling more meaningful participation in collaborative design activities.

However, widespread implementation of 3D-Printing in education is still hindered by several barriers. These include high material costs, inadequate access to printers, a steep learning curve for model creation, and a lack of staff training (PrintLab 2023; Hollmann *et al.* 2025). Participants in this study echoed these concerns, particularly about printer reliability, construction of models and time-intensive use of the models in a workshop format. In under-resourced South African institutions, these barriers are exacerbated by infrastructural challenges and outdated curricula (Mashwama & Madubela 2025).

From a methodological perspective, Design-Based Research (DBR) is effective in navigating these complexities. Its iterative, participatory design structure enabled the research team to adapt to contextual constraints while co-developing sustainable, curriculum-aligned solutions. The literature supports this model's utility in similar technology integration efforts (Reeves 2006, in Kim and Park 2023; Narayan, Herrington & Cochrane 2019).

In sum, this study's findings contribute both empirical data and theoretical reinforcement to the discourse on digital disruption in design education. While ETaSTs present exciting pedagogical affordances, their full realisation depends on strategic investment, structured design processes, and stakeholder collaboration.

Methodology

This study utilised a Design-Based Research (DBR) methodology, structured into four phases: problem identification, iterative intervention design, implementation and refinement, and evaluation (Figure 2).

Figure 9: Adopted DBR four-phase method, an adjusted version of the four-phase Reeves model (Narayan, Herrington & Cochrane 2019)

The intervention was deployed at a South African university of technology with a population comprising three lecturers and approximately 200 undergraduate students from four different programmes. The selection of these diverse disciplines (Mechanical Technology, Physical Science Pedagogy, Ceramics: Sculpture, and Electrical Engineering) was based on a combination of practical reasons, including departmental interest and existing collaborations, and a research rationale to explore the applicability of ETaSTs across a broad spectrum of design-related fields within the university of technology. The common thread across these disciplines is their engagement with design education, making them suitable for this study.

To contextualise these interventions, each participating discipline engaged with 3D-printed artefacts purposefully designed to align with its specific curricular outcomes and pedagogical objectives. Within Electrical Engineering, students constructed a 555-timer circuit using modular 3D-printed components that supported conceptual understanding of circuit logic and systems integration. The Physical Science Pedagogy and Mechanical Technology modules investigated motion and forces through a 3D-printed catapult model, selected for its capacity to translate abstract scientific principles into embodied, experiential learning. In Ceramics: Sculpting, students explored the concept of negative space and structural balance through engagement with a Henry Moore-inspired model and a vertebra-based 3D print, which functioned as tactile references for form, proportion, and mass. Each artefact was refined to optimise tactile interaction and pedagogical efficacy. Students participated in successive design cycles, providing feedback that shaped the final artefacts, ensuring a collaborative, design-centred learning process.

Data were collected via pre- and post-intervention surveys, observational field notes, open-ended questionnaires, and literature reviews, with thematic coding and triangulation conducted in Atlas.ti. Ethical clearance was secured, and all participants provided informed consent, with voluntary participation, data anonymisation, and the right to withdraw without penalty assured. The following section breaks down the four phases in summary by illustrating the iterative design process from one of the interventions (Electrical Engineering). The complete development of each subject area is unpacked in the Results and Discussion section later in this paper.

Phase 1

In Phase 1, the learning problems were identified and explored through consultations with the stakeholders (lecturers and students). The initial literature review supported the problem statement and identified a learning solution for each of the disciplines' outcomes and objectives (Figure 3).

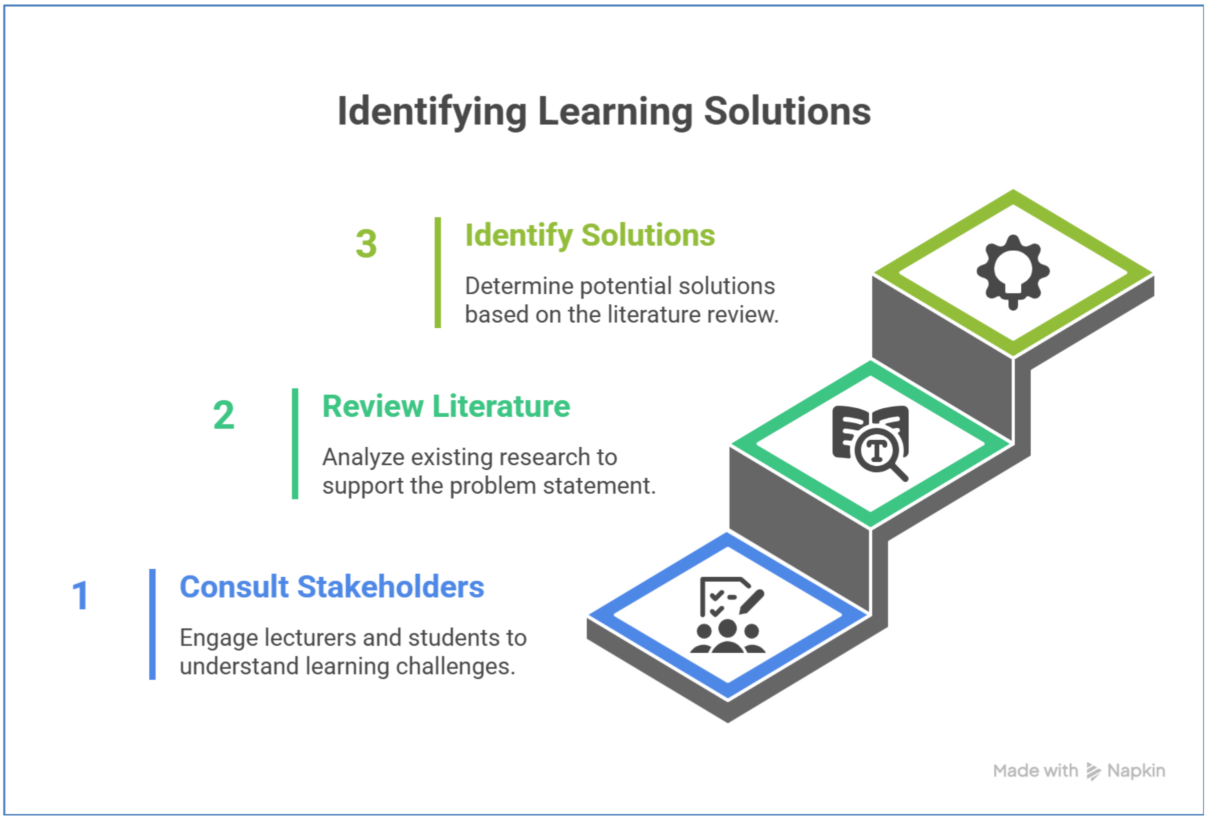

Figure 10: Examining problems to identify learning solutions

Phase 2

Phase 2 consisted of the second round of literature reviews to support the design and development of the educational intervention through the co-creation of draft design principles for ETaST in partnership with lecturers. Figure 4 illustrates how the original electrical diagram (a) was altered to accommodate 3D-Printed artefacts (b), leading to the first prototype 555-timer circuit design (c).

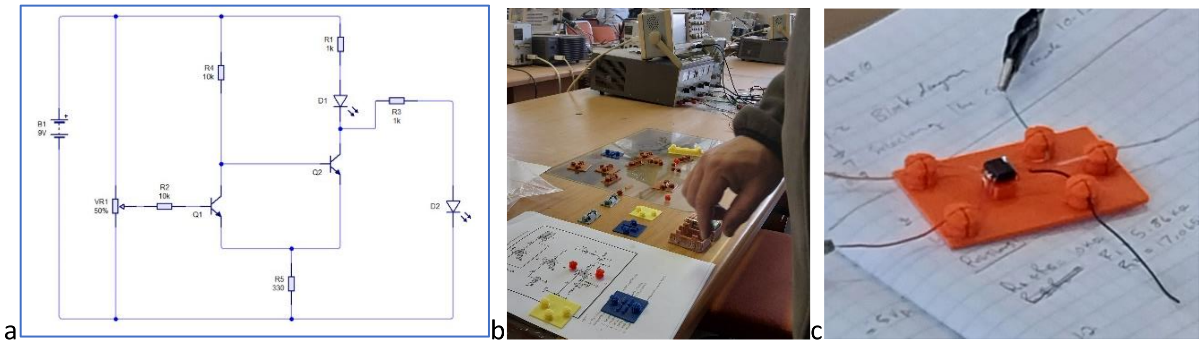

Figure 11: Development of the educational intervention to construct a 555-timer circuit through 3D-printed artefacts

Phase 3

Phase 3 examined the draft principles for ETaST in the first cycle (iteration), where data collection and analysis occurred (Figure 5a-b), followed by identifying areas that can be improved. This second cycle was a refinement and response to the findings and insights from the first cycle, aligning with the iterative nature of DBR (Figure 5c-d).

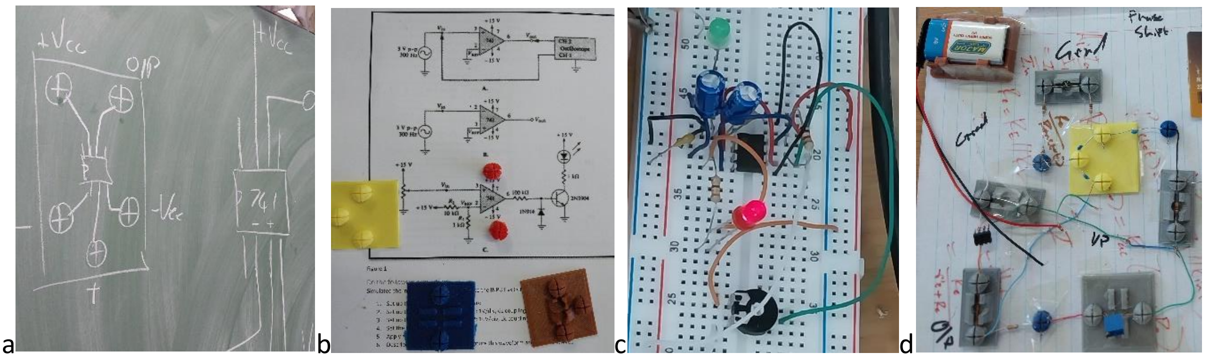

Figure 12: First iteration data collection followed by analysis to identify improvements to the artefact design

Phase 4

Phase 4 reflected on the design principles tested in phase 3 by refining the principles and establishing how enhanced solutions can be implemented to contribute to theory and practice (Figure 6a-b). In this phase, the original stakeholders were contacted to share the final design principles for implementation (Figure 6c). Methods 1 and 2, therefore, are based on the planning and development stages, while Methods 3 and 4 executed specific learning material using design principles.

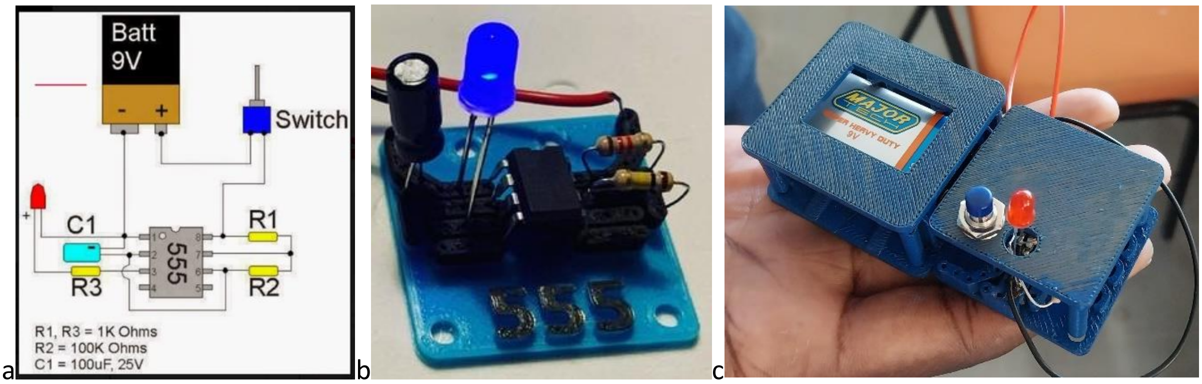

Figure 13: Implement refined design principles to investigate improvements

Once the interventions were completed, a final, extensive thematic literature review was conducted on the principal concepts that emerged from the qualitative coding in Atlas.ti *(refer to Post-Intervention Literature review)*. This final analysis aimed to cross-reference and corroborated recurrences identified in the literature from 2020 to 2025. These recurrences, in the form of ETaST affordances, enhance the validity of the research and underscore its significance in Design Education.

Results and discussion

Introduction

This section presents the comprehensive findings of the study, detailing the insights gathered from both pre-intervention surveys and post-intervention reflections. It begins by outlining the initial perspectives of lecturers and students regarding Educational Technology and Experiential Learning (ETaST), including their familiarity, current integration of technology in pedagogy, and anticipated benefits and challenges. Subsequently, the section delves into the observed impacts and challenges during the intervention phase, drawing from student feedback. The emphasis will be on the outcomes of the 3D projects and how ETaSTs facilitated these, including examples of student work and the impact on learning. Finally, it integrates a post-intervention literature review to contextualise and reinforce the empirical findings within the broader academic discourse on ETaSTs in design education.

Pre-intervention surveys

Lecturer pre-intervention surveys

The lecturer pre-survey included four participants interested in the ETaST workshop interventions (Figure 7). Only two lecturers were familiar with the ETaST concept, and three reported using technological tools such as LMS platforms and multimedia resources, with no prior use of tactile technologies. When asked about potential benefits and drawbacks, lecturers highlighted that ETaSTs could bridge theoretical and practical learning, enhance multisensory engagement, improve retention and skills, and support students with sensory impairments through customised learning aids. Concerns included limited training time, language barriers, classroom distraction, and resource constraints. To address these, lecturers recommended gradual integration through first-year pilot programmes, increased awareness, curricular alignment, and skill development for both staff and students.

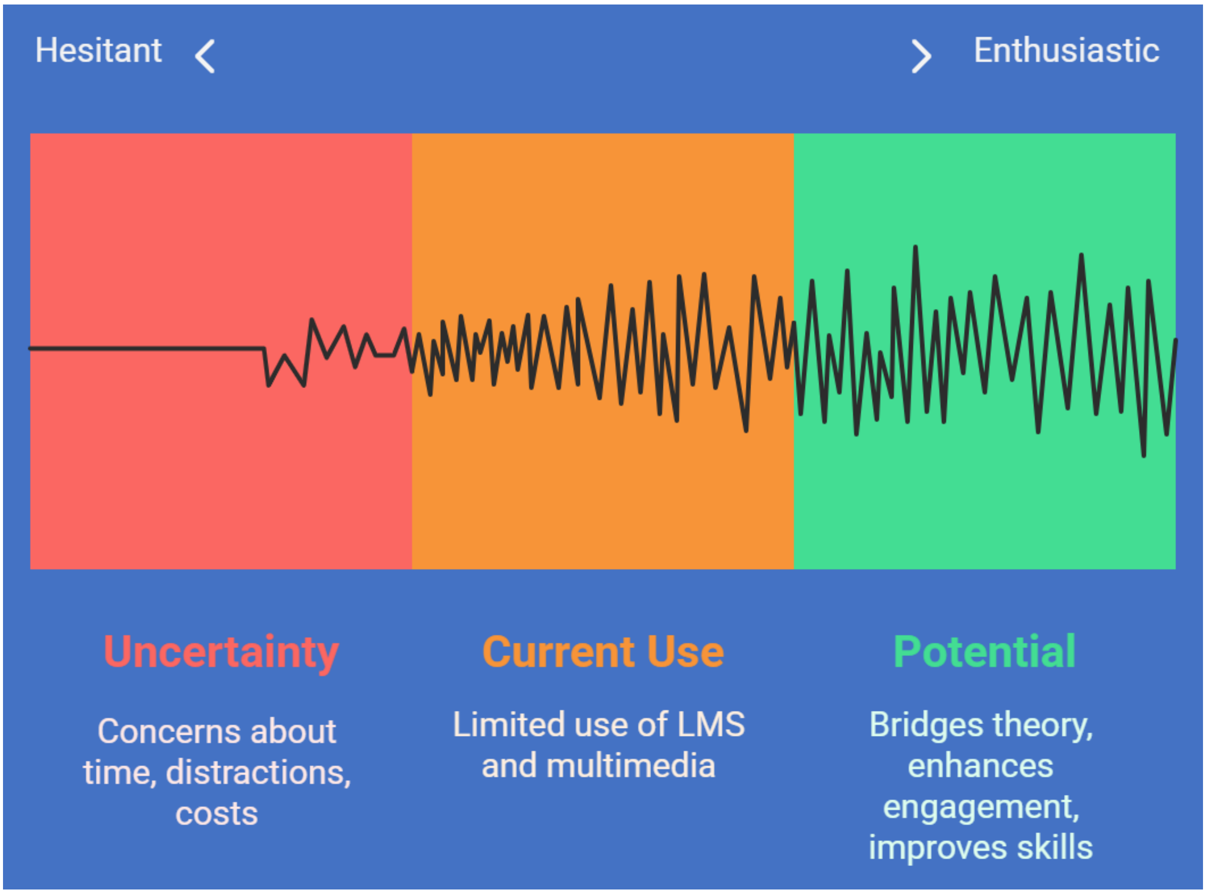

Figure 14: Lecturer perspectives on ETaST implementation: From hesitant to enthusiastic

Student pre-intervention surveys

Pre-intervention surveys across four modules (Mechanical Technology, Physical Science Pedagogy, Ceramics: Sculpture, Electrical Engineering) revealed no prior ETaST experience among students. Attitudes were generally positive or uncertain. Perceived advantages included enhanced understanding and engagement, while disadvantages cited cost, technical issues, and time constraints. Belief in improved learning varied, with some concerns about critical thinking and the creative process (Table 1).

The findings suggest that ETaSTs are not merely additive tools but possess disruptive potential by fundamentally shifting pedagogical practices from traditional, often passive, lecture-based instruction to active, hands-on, and experiential learning. The observed 'bridging the gap between theoretical concepts and practical applications' and students 'engaging with subject content in a physical way' represent a departure from conventional methods, demanding a re-evaluation of classroom dynamics and instructional design. This disruption is further evidenced by the lecturers' initial 'uncertainty with time frames to train students' and 'fear of ETaSTs being distractive,' indicating a challenge to established routines and control.

Table 10: Student pre-intervention survey results by module

Module	Total Respondents	Prior Experience with ETaSTs	Attitude towards ETaSTs	Perceived advantages	Perceived disadvantages	Belief that ETaSTs would improve the learning experience
Mechanical technology	18	0% (None)	72% Positive, 28% Uncertain	• Increased understanding of subject knowledge • Possible faster retention timeframes • Enhanced engagement during the lessons • Engaged with subject content in a physical way	• High cost of 3D models • Lack of technical support • Time-consuming in short lessons • Potential interference with critical thinking processes	62% Yes, 38% No
Physical science pedagogy	13	0% (None)	54% Positive, 46% Uncertain	• Possible improvement in retention • Engaging with physical objects leads to a deeper understanding	• Uncertainty towards time constraints • Technical problems while using the ETaST models	46% Yes, 23% No, 31% Uncertain
Ceramics: sculpture	10	0% (None)	70% Positive, 30% Uncertain	• ETaST as a new toolset for creative skills • Produced more effective and convenient forms of creation	• Uncertainty towards time constraints • Cost and availability of material • Use of ETaST will remove their creative process	50% Yes, 20% No, 30% Uncertain
Electrical engineering	2	0% (None)	100% Positive, 0% Uncertain	• ETaSTs could improve their skills • Make their learning experience easier	• Time constraints • Cost	100% Yes

Intervention survey reflections

After the first intervention, students in each module completed a survey, with results presented in the same order as the pre-intervention section.

Mechanical Technology Pedagogy Module: Forty students and one lecturer participated. Fifty-four percent reported active involvement, attributing this to component assembly that enhanced content knowledge, calculation skills, group collaboration, and the practical application of theory. Physical activity improved recall and made learning more enjoyable. Twenty-eight percent rated the intervention as very effective, while others were uncertain or partially positive. Reported benefits included greater engagement, motivation, retention, and conceptual understanding, with all participants recommending ETaSTs. Challenges included technical issues (41%), lack of pre-training (12%), and curriculum integration concerns (Figure 8).

Physical Science Pedagogy Module: Due to a lecturer's departure, only two of the twenty-three students completed the survey, yet both offered meaningful insights. They reported strong involvement, noting that component assembly accelerated knowledge formation and enhanced enjoyment. Both rated the intervention as very effective, citing increased engagement, motivation, and retention. Technical difficulties with model assembly were the main challenge (Figure 8).

Ceramics: Sculpture Module: Four of thirty-six students completed the survey, three of whom felt actively involved in the intervention. Half rated it as very effective, citing enhanced engagement, motivation, and understanding of learning outcomes. All participants recommended ETaSTs for creative disciplines. Reported challenges included insufficient pre-training and uncertainty about integrating ETaSTs into fine art curricula (Figure 8).

Electrical Engineering Module: Fourteen of eighteen students responded, with 60% reporting active involvement. Students successfully produced circuit units but encountered issues with non-standard 3D-printed components. Effectiveness was rated as very effective by 21%, while 43% were unsure, 29% partially positive, and one found it ineffective. Benefits included greater engagement, motivation, retention, and comprehension; all endorsed ETaST use. Challenges included technical issues (43%), lack of pre-training (38%), and curriculum integration difficulties (21%) (Figure 8).

Collectively, these challenges—lack of formal curriculum integration, educator training gaps, and student concerns about incorporating ETaSTs—highlight a disruption in traditional curriculum design and educator roles. ETaSTs necessitate a shift from content delivery to hands-on exploration, requiring educators to transition from instructors to facilitators. The observed benefits align with Kolb's Experiential Learning Theory, where tactile engagement supports 'Concrete Experience' and 'Active Experimentation,' deepening learning outcomes through practical application and physical interaction.

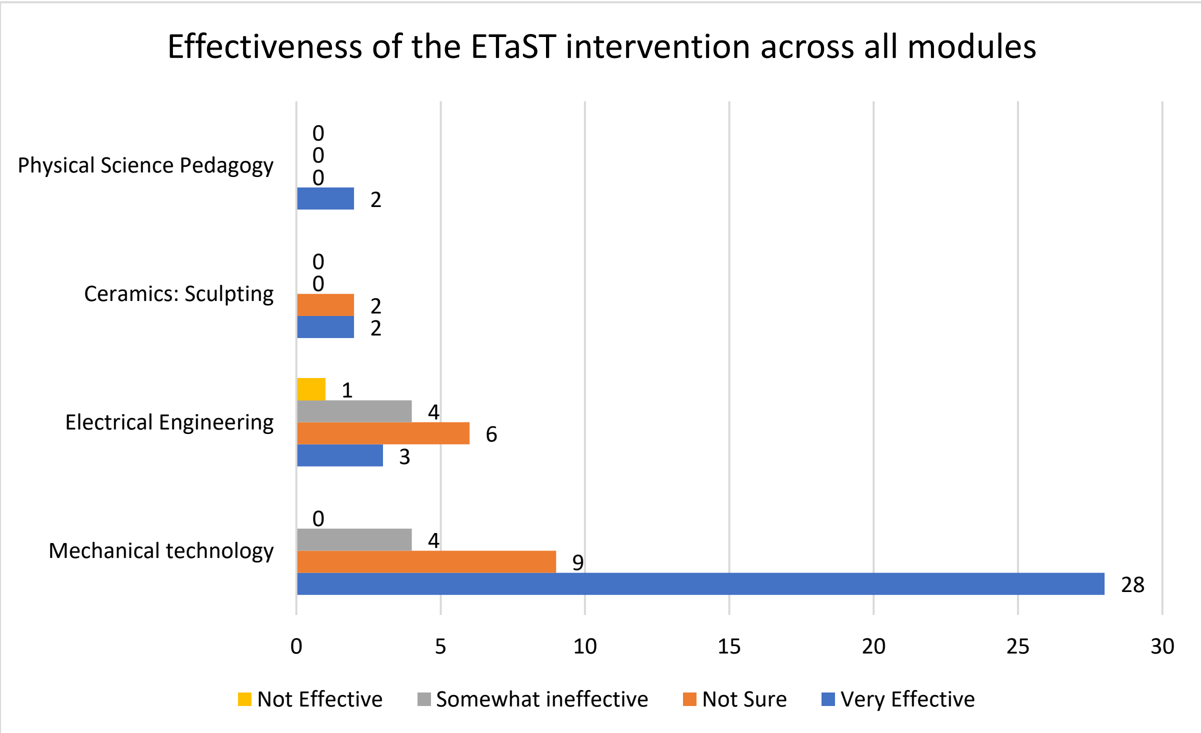

Figure 15: Scaling chart of the effectiveness of the ETaST interventions

Evolution of 3D printed artefacts or "iterative design outcomes"

In order for the reader to understand the use of 3D-Printed models as ETaSTs, the following section demonstrates the evolution of the artefacts through the iterative design processes. The integration of the 3D-printed artefacts into lesson planning was guided by the design principles established during the DBR cycles, ensuring that each artefact served a clearly defined pedagogical function within its respective module. Lesson plans were adapted to embed the artefacts as central tools for experiential learning rather than supplementary demonstrations. In this way, students engaged directly with the printed models during concept introduction, exploration, and assessment activities.

Mechanical technology and physical science pedagogy

In the Mechanical Technology and Physical Science Pedagogy modules, the 3D-printed catapult facilitated inquiry-based learning through the measurement of force and motion. The original design was based on the Da Vinci catapult design (Figure 9a-b) and sourced from a Creative Commons open-source model on Thingiverse.com (Figure 9c). Students found the artefact difficult to assemble due to a lack of technical skills (Figure 9d), which prompted a redesign to a more simplified design (Figure 9e). Once a simplified design was sourced from Thingiverse.com, the design was adjusted for effectiveness (Figure 9f-h).

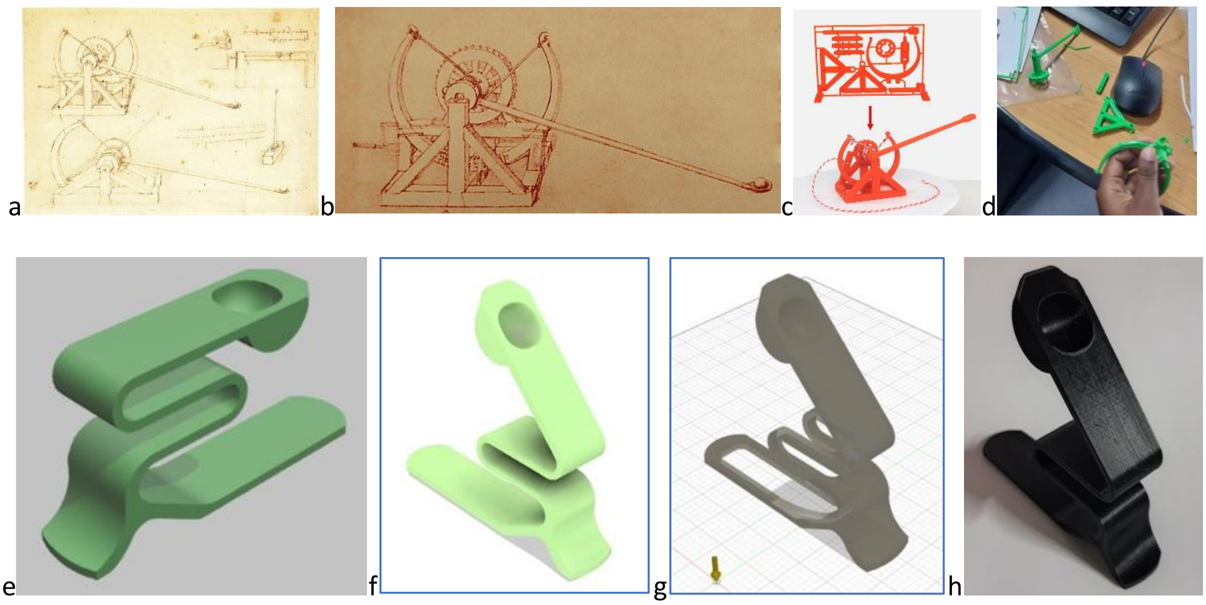

Figure 16: Iterative development of the artefact for motion and forces

Ceramics: sculpting

In Ceramics: Sculpting, students were provided with a lesson brief on the concept of negative space use in sculpting and how to integrate a plinth in the design (Figure 10a). 3D-Printed artefact designs were sourced from Thingiverse.com to illustrate space and form, which were used in their planning phase (Figure 10b-d). These Henry Moore-inspired and vertebra-based models functioned as tactile exemplars for exploring negative space and compositional balance. The final artworks were then produced in plaster-of-Paris sculptures (Figure 10e).

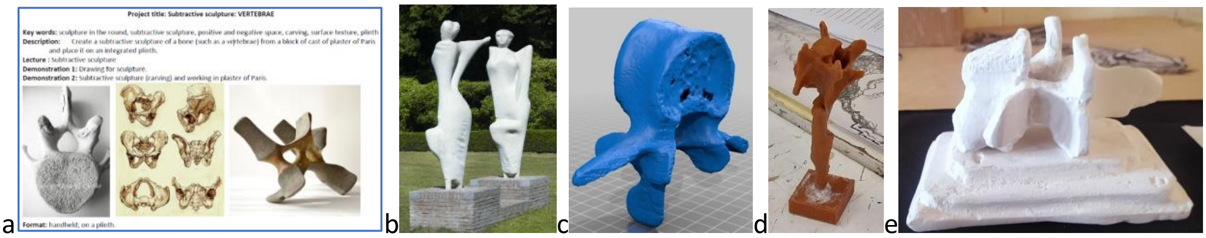

Figure 17: Iterative development of the artefacts used to investigate space, form and composition

Electrical engineering

In Electrical Engineering, the 555-timer circuit assembly provided a tangible interface for testing theoretical principles of circuitry. The first iteration investigated the format of designing a circuit to house a 555-timer (Figure 11a-b), from where a 3D-printed model was sourced on Thingiverse.com (Figure 11c). In the following iteration, the 555-timer circuit went through multiple design stages to house all the components in the design brief (Figure 11d-e). A final design was then constructed to clean up the model design for ergonomic use (Figure 11f-h).

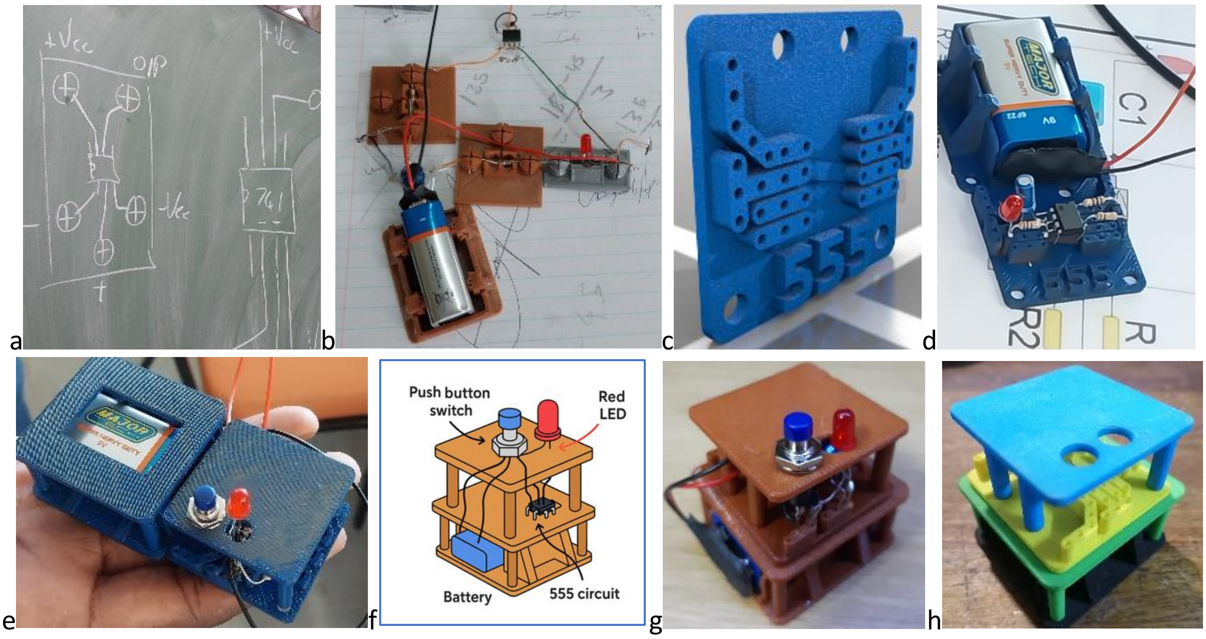

Figure 18: Iterative development of the artefacts used in a commercial design brief, combining design with the theoretical objectives of constructing a functional 555-timer circuit

Across all modules, the artefacts promoted student engagement by transforming abstract or theoretical concepts into manipulable, sensory experiences that fostered collaboration, reflection, and iterative problem-solving. These activities exemplify the pedagogical affordances of ETaSTs discussed earlier—namely, the capacity to bridge theory and practice, enhance multisensory engagement, and support active knowledge construction through design interaction.

Post-intervention surveys

In the final survey, all module participants were asked to complete the questions in reflection of the whole experience. This section summarises the concluding survey results.

Of the overall population (n=200), 44 students/lecturers participated and were asked to describe their experience in the co-creative process for including ETaST. Fifty-nine percent of the respondents described the process as a very good experience. Some indicated that the intervention helped them develop new skill sets to retain subject knowledge and made them feel like active participants, rather than only being passive observers.

> Participant 19: In the co-creative intervention for the bone project, I found collaboration process to be incredibly enriching, fostering devise perspective and innovative idea that led to a more comprehensive and affective solution, it was a rewarding experience combining collective expertise to address complex challenges in bones….

> Participant 27: It was more fun and i got to learn new things. I was working with different people and we were all listening to each other, sharing our ideas, assisting each other where possoble. It was also educational and i got to see how to join a model starting from scratch.

> Participant 34: The experience was amazing. I am privileged to have been taken through that process. I got to learn and gain ideas from that experience. the teacher was also amazing and helped us with warming up to his teaching style.

Participants were next asked about challenges encountered during the co-created ETaST intervention. Half reported experiencing some difficulty, often stemming from preconceived assumptions about the co-creative process or from the use of traditional materials such as lesson content and art supplies. Despite these issues, 81% of respondents agreed that the intervention positively impacted their learning experience.

Respondents were asked how to improve the intervention. Twenty-three percent preferred it to remain unchanged, while others suggested enhancements such as using alternative materials (e.g., metal or ceramics), incorporating interactive elements like extended reality (XR), improving model quality, addressing time constraints, expanding projects across more modules, increasing user-centred design iterations, and ensuring greater transparency and stakeholder involvement.

Eighty-nine percent showed strong interest in future ETaST interventions, underscoring disruption of traditional pedagogy. The findings reveal key pedagogical benefits of ETaSTs in South African design education: fostering experiential learning that links theory and practice, enhancing engagement and spatial reasoning, and supporting inclusivity through tactile and sensory approaches. Lecturers and students alike noted improved understanding, skills development, and hands-on learning experiences

Conclusion

Realising ETaSTs' potential requires investment in infrastructure, curriculum redesign, and professional development, with future research focusing on broader disciplinary scaling. This study examined Embedded Tactile and Sensory Technologies as digital disruptions in South African design education through a Design-Based Research approach, evaluating a 3D-printing intervention grounded in Experiential Learning Theory. The intervention enabled students and lecturers to move from conceptual understanding to tangible outputs, fostering conceptual clarity, teamwork, and learner agency suited to 21st-century learning environments. Despite challenges such as limited equipment and expertise, these mirror global trends intensified by local inequalities. The study contributes a replicable framework for embedding ETaSTs in design education, highlighting their capacity to promote experiential learning, spatial reasoning, and engagement while underscoring the need for institutional support to overcome persistent barriers and realise their full pedagogical value.

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