From Studio to Society: A Hardware–Software–Heartware Framework for Interdisciplinary Design Innovation in the New World University

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The Asian Conference on Education 2025
Official Conference Proceedings

Abstract

This study investigates an interdisciplinary pedagogical model developed at the Singapore Institute of Technology (SIT) to address the growing complexity of global challenges through innovative higher education design. Implemented within the *Design Innovation* common module, the model engages students from nursing, engineering, computing, and allied health disciplines in solving authentic problems using the Critical Design Futures Thinking (CDF™) and Design Your Life (DYL) approaches. The framework guiding this initiative—the Hardware–Software–Heartware (H–S–H) Tri-Layer Framework—conceptualizes learning as a dynamic interplay of physical, curricular, and socio-emotional dimensions. *Hardware* encompasses the new SIT campus as a living laboratory that integrates the built environment, digital infrastructure, and community contexts. *Software* represents the curriculum as an adaptive system designed through iterative learning sprints, incorporating empathy-based problem framing and ethical Generative AI integration. *Heartware* focuses on the socio-emotional and cultural layers that nurture collaboration, reflective practice, and ethical awareness. A diverse array of data sources was utilised to ensure comprehensive insights and triangulation. Data sources included curriculum material, student module feedback and project deliverables, sampled from module cohorts across two consecutive trimesters (AY2024 Trimester 2 and 3). Through thematic analysis and vignette development, the study aims to illustrate how the H–S–H framework operationalizes interdisciplinarity as an active interaction among space, structure, and culture. The insights are expected to inform the framework's scalability for general education as well as Continuing Education and Training (CET) programmes, contributing to a broader vision of campuses as innovation studios and societal prototyping platforms.

Keywords: Hardware–Software–Heartware (H–S–H) framework, interdisciplinary pedagogy, innovation education

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Introduction

The 21st century presents an unprecedented confluence of challenges, from climate change and global pandemics to rapid digital transformation and complex socio-political upheavals. Addressing these "wicked" problems demands more than isolated disciplinary expertise or linear problem-solving approaches; it calls for profoundly integrated, interdisciplinary forms of learning, research, and innovation. Consequently, higher education institutions globally are under increasing pressure to re-envision their core mission: not merely to disseminate knowledge, but to cultivate graduates who can lead, collaborate, and innovate across diverse professional, cultural, and technological landscapes.

This imperative for transformation is set against a backdrop of what has been termed "fast academia" – a neoliberal, performance-driven environment often characterised by relentless pursuits of productivity, competitiveness, and accelerated expectations. Such pressures can inadvertently erode the very "human(e) elements" of learning and teaching, challenging the preservation of empathy, kindness, and compassion within educational settings. In response, there has been a growing advocacy for "slow movement" principles in academia and a renewed emphasis on humanising pedagogies that prioritise dignity, critical consciousness, kindness, humility, empathy, and love as foundational ideals for humanising interactions.

The Singapore Institute of Technology (SIT) stands as a microcosm of this global trend and a vibrant testbed for innovative educational models. With students and faculty representing nearly forty diverse degree programmes ranging from engineering and nursing to allied health, computing, and business. SIT provides a unique living laboratory for cultivating interdisciplinary capabilities. Central to SIT's pedagogical philosophy is the Hardware–Software–Heartware (H–S–H) tri-layer framework, a distinctive approach that moves beyond superficial multidisciplinary efforts to foster genuine integration. This framework insists that true interdisciplinarity and holistic learning emerge from a dynamic, symbiotic interaction between three interdependent layers: the physical and digital infrastructure ("hardware"), the curriculum design and pedagogical processes ("software"), and the deeply social, ethical, and affective dimensions of student-lecturer interactions (*heartware*).

This paper argues that the H–S–H framework offers a powerful, actionable model for designing and evaluating learning environments capable of meeting both the cognitive and socio-emotional demands of 21st-century learning and work. It is a deliberate framework that emphasises that a multi-layered, dynamic interaction promotes compassion, resilience, and ethical imagination that are necessary for driving innovation.

This paper proceeds with the following objectives:

1. To situate the H–S–H Tri-Layer Framework within international and local literature on interdisciplinary innovation, campus ecology, and social-emotional learning.
2. To detail how the H–S–H framework is operationalized within the SIT Design Innovation module, including mechanisms for *hardware*, *software*, and *heartware* integration in both design and implementation.
3. To illustrate, using data and vignettes from recent module cohorts, how students and educators experience and enact interdisciplinarity when multiple domains, stakeholders, and forms of expertise collide and collaborate.
4. To analyse the impacts, challenges, and enabling conditions for wide-scale adoption of the H–S–H framework, including institutional, pedagogical, and cultural levers and potential transferability to other general education and continuing education contexts.

5. To offer a roadmap and recommendations for scaling H–S–H in diverse educational and societal settings, informed by current best practice and emerging scholarship.

By leveraging the lived experience of an applied university's common module and global research evidence, this paper aims to illuminate a path towards genuine interdisciplinary learning and institutional transformation, positioning universities as sites of continual co-creation, social impact, and lifelong learning.

Literature Review

The H–S–H framework draws on literature advocating holistic, human-centred education across interdisciplinary education, project-based/authentic learning, grid–group dynamics, and university infrastructure and campus design.

Evolution of Interdisciplinary Education

Interdisciplinary education in higher education responds to complex societal challenges by moving from disciplinary coexistence to purposeful epistemic integration that combines knowledge, methods, and ontologies for practice-based solutions (Keenan, 2020; Slothuus et al., 2025). Contemporary frameworks stress disciplinary grounding, epistemic agility, humility, and collaboration in authentic, problem-rich environments, yet remain constrained by governance, faculty preparedness, and reward systems, while students face identity tensions and uneven team dynamics (Schijf et al., 2023; Strain & Potter, 2012; Visscher-Voerman et al., 2025; Xu et al., 2022).

Project-Based Learning (PBL) and Authentic Learning

PBL is a key driver of interdisciplinary competence, engaging learners in real-world, collaborative, and outcomes-oriented inquiry that enhances motivation, deep learning, and work readiness (Aksela & Haatainen, 2019; Barell, 2007; Barron & Darling-Hammond, 2008; Boss & Krauss, 2007; Evenddy & Gailea, 2023; Gantogtokh & Quinlan, 2017; Kamanga, 2024; Klaassen, 2018; Larmer & Mergendoller, 2015; Silma et al., 2024; Warr & West, 2020). Its effectiveness depends on the interplay of software (curriculum), hardware (institutional structures and infrastructure), and heartware (affective-relational dynamics), supported by authentic assessment, reflection, and external partnerships (Barrett & Naughton, 2014; Ghani et al., 2021; Kek & Huijser, 2017; Tan, 2022).

Social-Emotional Learning (SEL) Cultivating the "Heartware"

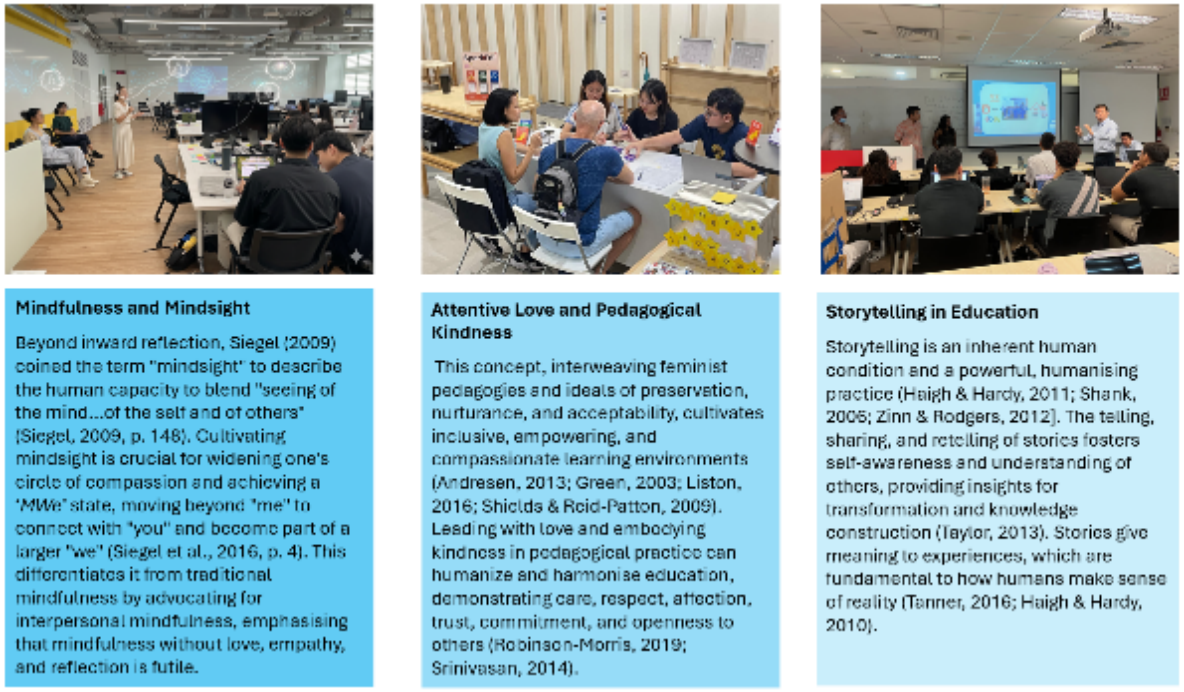
SEL constitutes the "heartware" that complements cognitive and technical learning by cultivating empathy, resilience, ethical judgment, collaboration, self-regulation, and inclusion, thereby supporting interdisciplinary practice, wellbeing, and equity (Conley & Donahue-Keegan, 2024; Ibarra, 2022; Lisciandro et al., 2016; Martinez & Gomez, 2024; Tan, 2022; Van Pham, 2024). Tan's "Heartware for the Compassionate Teacher" framework links three domains: mindfulness and mindsight (Siegel, 2009; Siegel et al., 2016; Smalley & Winston, 2010; Srinivasan, 2014), attentive love and pedagogical kindness (Antoniuk et al., 2021; del Carmen Salazar, 2013; Green, 2003; Liston, 2016; Shields & Reid-Patton, 2009), and storytelling as humanizing practice (Andresen, 2013; Benade, 2019; Haigh & Hardy, 2011; Robinson-Morris, 2019; Savvidou, 2010; Sferrazza, 2018; Shank, 2006; Taylor, 2013; Tanner, 2016; Zinn & Rodgers, 2012).

Mindfulness nurtures presence and reflective awareness (Smalley & Winston, 2010); attentive love enacts care through respect, empathy, and pedagogical trust (Antoniuk et al., 2021; del Carmen Salazar, 2013; Shields & Reid-Patton, 2009); and storytelling situates learning within narrative and meaning-making processes (Haigh & Hardy, 2011; Tanner, 2016; Taylor, 2013). Collectively, these approaches humanize education, reinvigorate the moral purpose of teaching, and counter the instrumental tendencies of neoliberal academic cultures (del Carmen Salazar, 2013; Freeman et al., 2020).

This triadic synthesis of interdisciplinarity, authentic learning, and heartware pedagogy delineates a humane and future-oriented pathway for higher education. It not only equips graduates with integrative thinking and adaptive expertise but also fosters compassion, relationality, and civic agency as defining virtues of contemporary scholarship.

Figure 1

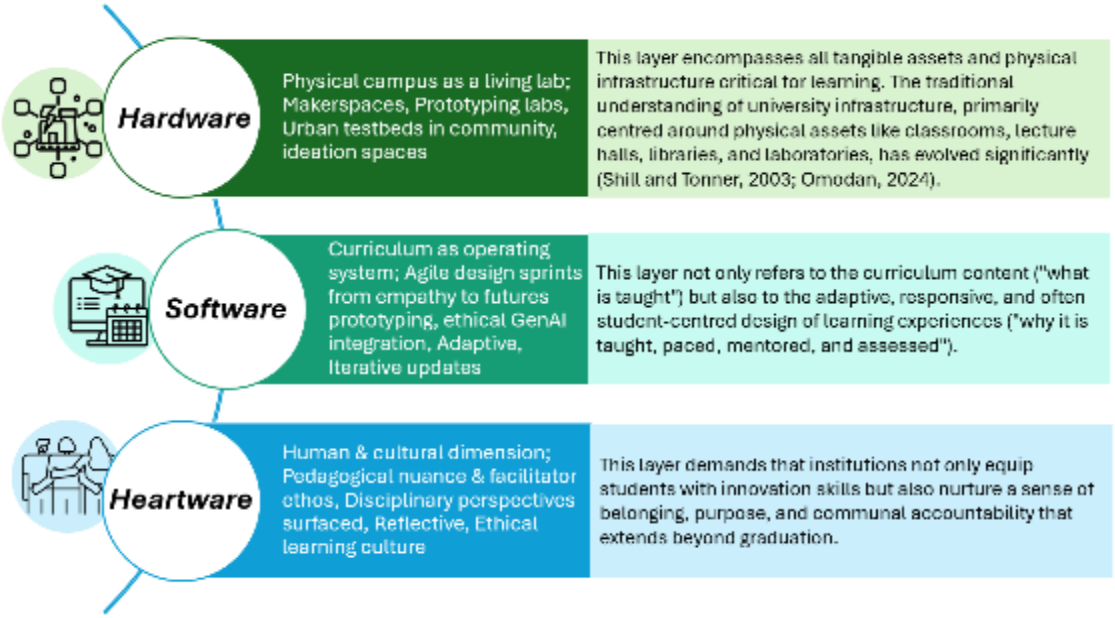
Heartware Elaborated



Conceptual Model

The Hardware–Software–Heartware (HSH) tri-layer framework is a conceptual model which stands as a bold synthesis, integrating traditional campus strengths with experimental learning theory to address the complex demands of 21st-century education. It is built upon an insistence that interdisciplinarity is not merely superficial co-location but a profound, multi-layered interaction, aiming for campus-wide transformation rather than temporary overlays. This triad functions as a comprehensive framework aligning material, cognitive, and emotional infrastructures for the common good, moving beyond the notion of universities as mere “learning factories” to “living communities”. The HSH framework delineates three interdependent and synergistically operating layers (see Figure 2):

Figure 2
Hardware–Software–Heartware (HSH) Framework



- Hardware: Historically, these spaces were epi-centres of intellectual pursuits, academic interactions, and community building, reflecting societal values and academic philosophies (Bogart, 2022; Gevorgyan et al., 2020). However, the digital age, with the advent of the internet, online learning platforms, and digital libraries, has fundamentally altered knowledge dissemination and consumption, necessitating a re-evaluation of infrastructural orientations (Kaziev et al., 2020; Song et al., 2006). The 21st-century university infrastructure is now characterized by a complex interplay between physical assets and digital evolution. The concept of a "campus as a living lab" embodies this evolution, where physical and digital affordances provide real-time, authentic contexts for innovation, engagement, and knowledge translation (Hansen, 2016; Pilon et al., 2020; Save et al., 2021).
- Software: This layer focuses on pedagogical and instructional design elements, including teaching approaches, best practices, curriculum development, content, and assessment. It advocates for a departure from rigid, siloed learning environments towards collaborative and flexible arrangements that facilitate project-based learning, cross-disciplinary collaborations, and real-world problem-solving.
- Heartware: As the most distinctive and arguably most critical layer in education, *heartware* focuses on the cultivation of social capital, empathy, ethical reasoning, and a sense of "ownership" and care for both learning and community outcomes. It represents the "underlying values, attitudes, and "inner infrastructure" of a community or institution" (Antoniuk et al., 2021; Hackman & Reindl, 2022; Ignatovitch, 2016; Tan, 2022; Young, 2020). It counters the neoliberal tendency to view education instrumentally, shifting towards humanistic, dialectical activities and intrinsic values.

These three layers are not treated as sequential steps but as a dynamic interplay, constantly rebalanced based on evolving needs and feedback, leading to "tripartite" projects where new campus infrastructure, curriculum construct, and SEL-anchored programming co-evolve.

Method

The study employed a direct qualitative content analysis design. Direct qualitative content analysis offers distinct benefits for studying the H–S–H framework, particularly given its interdisciplinary and context-embedded nature. This approach enables the identification and interpretation of both manifest content, such as explicit references to framework components and latent content consisting of underlying meanings, values, and patterns of interaction, sourced from a rich array of qualitative data such as module feedback gathered from students and artefact analysis. This approach prioritises the systematic extraction of data-driven themes directly related to predetermined categories of the H–S–H framework, while remaining open to emergent themes that further refine the model. This technique also enhances transparency and replicability in coding, reduces interpretive ambiguity, and provides rigorous support for linking qualitative evidence to educational theory and practice (Chueh & Kao, 2024).

Context and Participants

SIT mandates the Interdisciplinary Design Innovation module for students from thirty-nine undergraduate programmes. The research participants include cohorts from trimesters two and three of the Academic Year 2024, encompassing over 2,000 students from diverse fields such as engineering, allied health, nursing, computing, and business, alongside more than twenty instructors. The module is delivered within SIT's Punggol campus, a site explicitly designed to support collaborative, interdisciplinary, and hands-on innovation, thereby embodying the *hardware* dimension of the H–S–H framework.

Data Sources

A diverse array of data sources was utilised to ensure comprehensive insights and triangulation. Data sources included curriculum material, student module feedback and project deliverables, including presentation slides, prototypes (physical, digital, or process-based) and videos, sampled from module cohorts consisting of 24 degree programmes, collected over two academic trimesters (AY2024 Trimester 2 and 3). The student module feedback dataset includes quantitative Likert-scale ratings (Q1–Q5 means) and qualitative free-text reflections.

Data Analysis

Data were analysed using thematic analysis, employing both deductive (pre-existing H–S–H categories) and inductive (emergent themes related to collaboration, reflection, and innovation barriers) approaches. Initial codes were developed to capture explicit instances of physical/digital infrastructure, curricular design/process elements, and socio-emotional or grid-group cultural dimensions. The coding process remained sensitive to emergent themes reflecting unanticipated enactments or challenges within interdisciplinary learning environments. Triangulation across data types strengthened the validity and credibility of findings. All procedures adhered to institutional ethical standards, with participant data anonymised and informed consent obtained for any supplementary research activities.

Ethics

The study strictly adhered to standard institutional review protocols (Approval-RECAS-0692_IRB_Exempted). Ethical considerations for this study were addressed under an exempted review process. Prior to analysis, all data were de-identified, and only aggregated results are reported, ensuring that no individual can be identified in any subsequent publication or presentation.

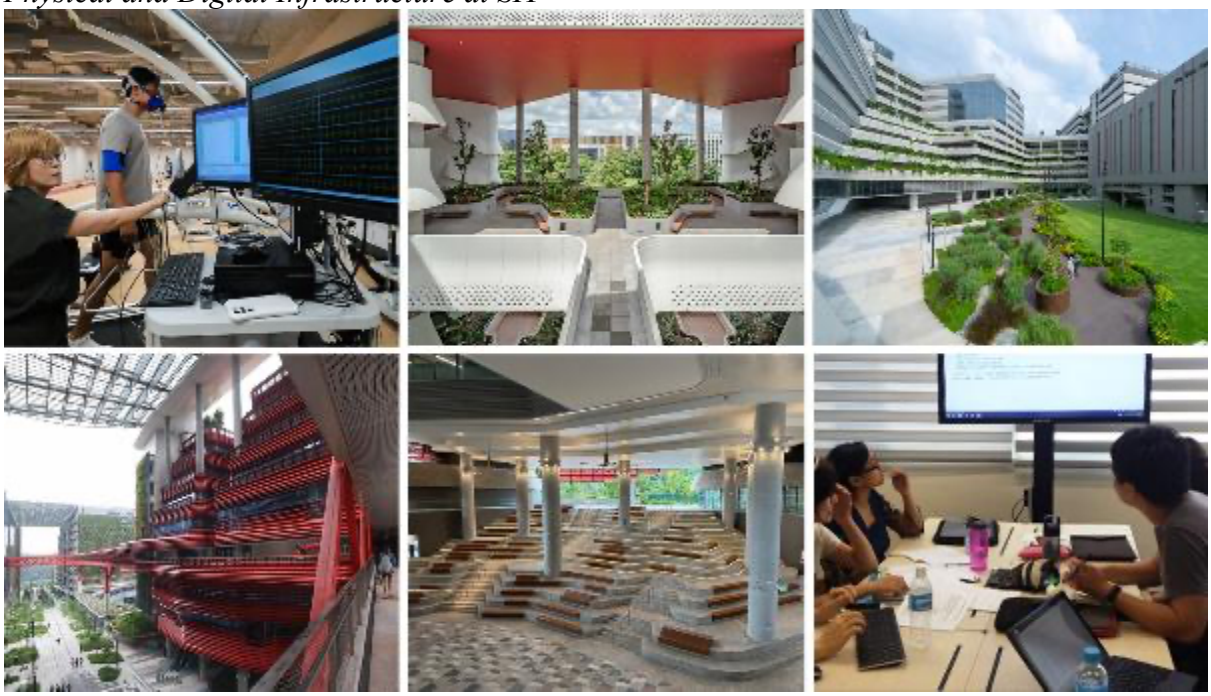
The Hardware–Software–Heartware (H–S–H) Framework in Practice

The operationalisation of the Hardware–Software–Heartware (H-S-H) Framework at SIT exemplifies a synergistic integration of physical campus design, curriculum architecture, and intentional socio-emotional learning. Each layer is designed to interact dynamically, fostering a robust learning ecosystem where deep interdisciplinarity and compassionate engagement can thrive.

Hardware

SIT's Punggol campus was purposefully conceptualised as an "urban testbed" for innovation, where the physical architecture and integrated technology infrastructure are explicitly aligned with pedagogical aspirations for collaborative, distributed, and real-world learning. This vision responds to the broader imperative for universities to redefine their infrastructural identity, harmonising tangible physical assets with the expanding world of digital evolution. The university owns state-of-the-art smart-eco buildings, flexible learning spaces, advanced laboratories, makerspaces, and physical technologies. See Figure 3.

Figure 3
Physical and Digital Infrastructure at SIT



Source: Straits Times; author

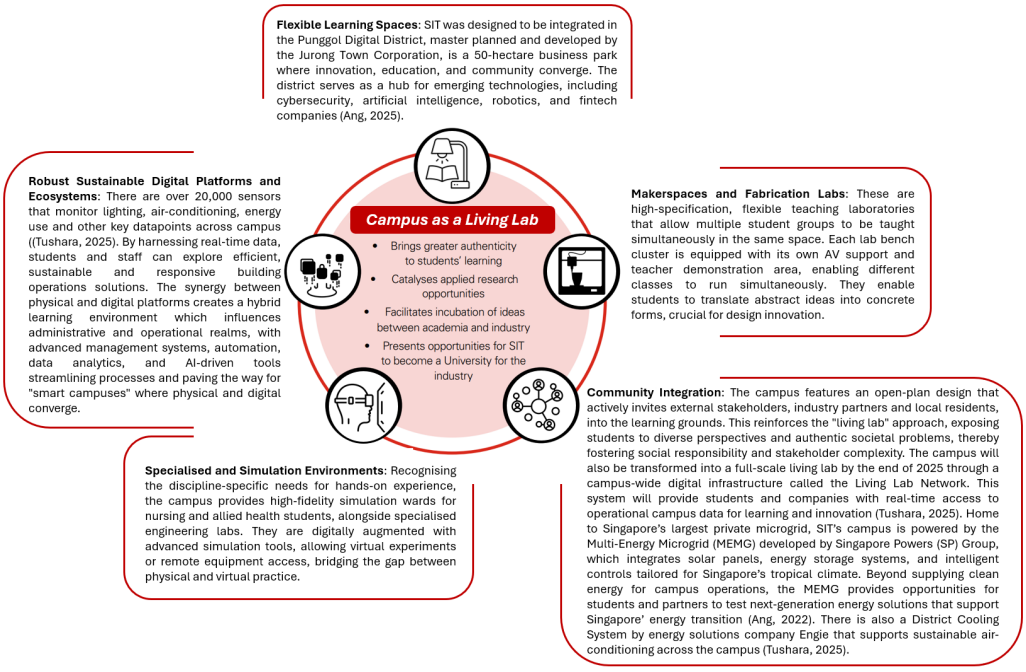
Key features of the *hardware* layer include flexible learning spaces configured to support fluid team formation, dynamic brainstorming, rapid prototyping, and a shift from rigid, siloed

settings to collaborative, inquiry-driven environments. Makerspaces and fabrication labs, equipped with 3D printers, electronics benches, and related tools, enable rapid iteration and the creation of tangible, cross-disciplinary projects. Specialised and simulation environments translate theoretical knowledge into realistic, immersive contexts, providing multi-dimensional learning experiences. The campus itself is conceived as a "Campus-in-the-Park," with SIT Campus Heart and SIT Campus Court spanning about 9 hectares—roughly 17 football fields—and integrating academic blocks with a conserved secondary forest that has been transformed into an accessible community park, thereby blending learning spaces with tropical landscapes.

A robust, sustainable digital ecosystem complements the physical infrastructure through cloud repositories, online collaboration tools, and learning management systems, supporting hybrid, asynchronous, and co-located teamwork and extending the reach and flexibility of the module. This intentional design ensures that physical spaces are not merely venues for knowledge reception but active incubators for innovation, creativity, and holistic development, seamlessly complemented by the dynamic capabilities of the digital realm. See Figure 4.

Figure 4

Hardware – Campus as a Living Laboratory

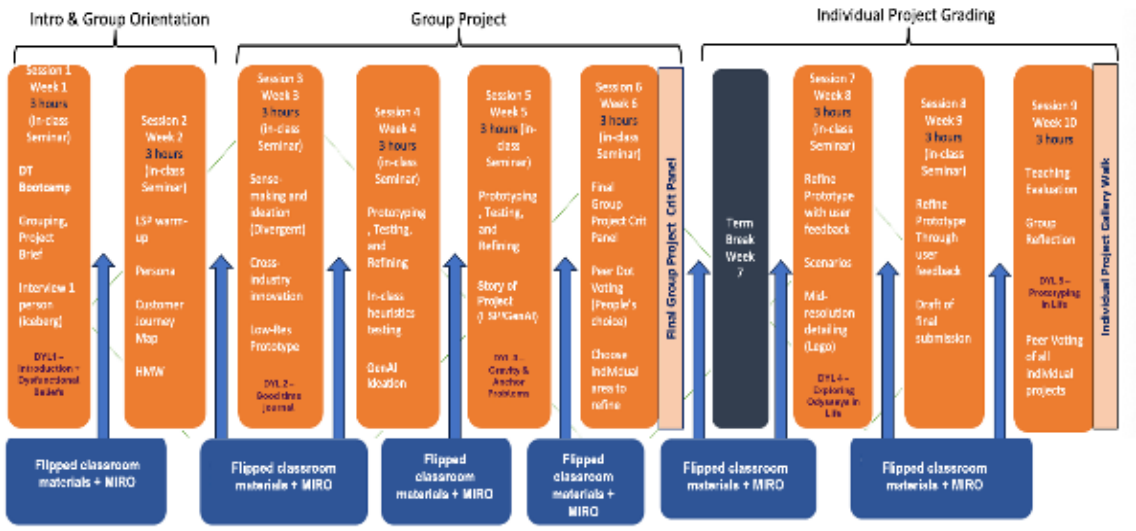


Software

The *software* layer, being the Design Innovation curriculum, is an adaptive, sprint-based programme that embeds human-centred design and iteration to mirror contemporary innovation practice and avoid rigid, siloed structures. It opens with empathy-based problem discovery, where students conduct user research and systems mapping (e.g., interviews and observations) to build deep, compassionate understanding of real-world challenges. Students then move through design thinking sprints, using methods such as the double-diamond model and Lego® Serious Play® to frame problems, ideate, prototype, and test, thereby normalising ambiguity and rapid learning from feedback (see Figure 5). Assessment is agile and authentic, organised around milestones, peer feedback, and reflective dialogue, which better

supports iterative learning than traditional high-stakes evaluations. Ethical and reflective practice is threaded throughout via ethical dilemma analyses, critical incident debriefs, and narrative feedback, ensuring that technical and collaborative skills are developed alongside ethical responsibility and critical consciousness, in line with a humanising educational ethos. This dynamic *software* layer ensures that students are not merely exposed to interdisciplinary problems but are actively equipped with the processes and mindsets to tackle them effectively, while simultaneously developing their ethical and collaborative sensibilities.

Figure 5
Software – Agile Curricula and Humanising Facilitation



Source: SIT, UDE2222

Heartware: Cultivating Socio-Emotional and Ethical Dimensions

The *heartware* layer at SIT is the most distinctive and operationally challenging component of the framework, intentionally developed alongside content and process to foreground the "human(e) elements" of learning and teaching (see Figure 6). It aims to cultivate social capital, empathy, ethical reasoning, and a deep sense of ownership and care for learning and community outcomes, countering the pressures of "fast academia" and supporting a more humanistic, equitable environment.

Key practices include metacognitive scaffolding, where Designing Your Life concepts, structured check-ins, and feedback nurture mindsight (awareness of one's own and others' mental states) and mindfulness, extending from inward reflection to an expanded sense of "we." An inclusive facilitation model brings together part-time educators from multiple disciplines who are trained in protocols for inclusive dialogue, conflict navigation, and "stretch" assignments, thereby modelling collective wisdom, mutual respect, and constructive handling of epistemic friction in interdisciplinary teams.

Engagement and storytelling are central: students choose topics on the future of work and life and collaborate with diverse stakeholders, using story-sharing and user journey mapping to surface complexity, social responsibility, and lived experience. Storytelling, grounded in "attentive love," links emotion, meaning, and understanding in authentically caring teacher–student relationships, creating inclusive, compassionate learning spaces. Overall, this *heartware* cultivation equips students not only with cognitive capacity for innovation but also

with the socio-emotional intelligence and ethical compass required to act as future change agents.

Figure 6

Heartware – Cultivating Social-Emotional and Ethical Dimensions

Dynamic Interplay for Interdisciplinary Learning

The H–S–H framework which surfaced at SIT, deliberately resists the siloing of these three layers. Instead, it fosters a dynamic, co-evolutionary interplay:

- Hardware and Software Co-evolution: Changes in physical learning spaces or digital platforms are rapidly mirrored in new module activities or pedagogical scaffolds. For example, the availability of makerspaces (*hardware*) directly enables agile design sprints (*software*).
- Hardware and Heartware Collision: The design of the campus to integrate with the community (*hardware*) provides authentic contexts for students to engage in empathetic user research and experience stakeholder complexity, driving the development of cultural humility (*heartware*).
- Software and Heartware Interdependence: The empathy-centric design methods and iterative feedback loops (*software*) are explicitly designed to cultivate collaborative mindsets, relational skills, and reflective practices (*heartware*). The facilitation from the instructors emphasises the critical interplay between curriculum elements (*software*) and the nuanced work of relational and ethical development (*heartware*).

This integrated approach ensures that the material, cognitive, and emotional infrastructures are aligned, allowing students to move beyond surface-level group work and form high-trust, adaptive micro-communities capable of solving complex problems with both technical proficiency and profound human compassion.

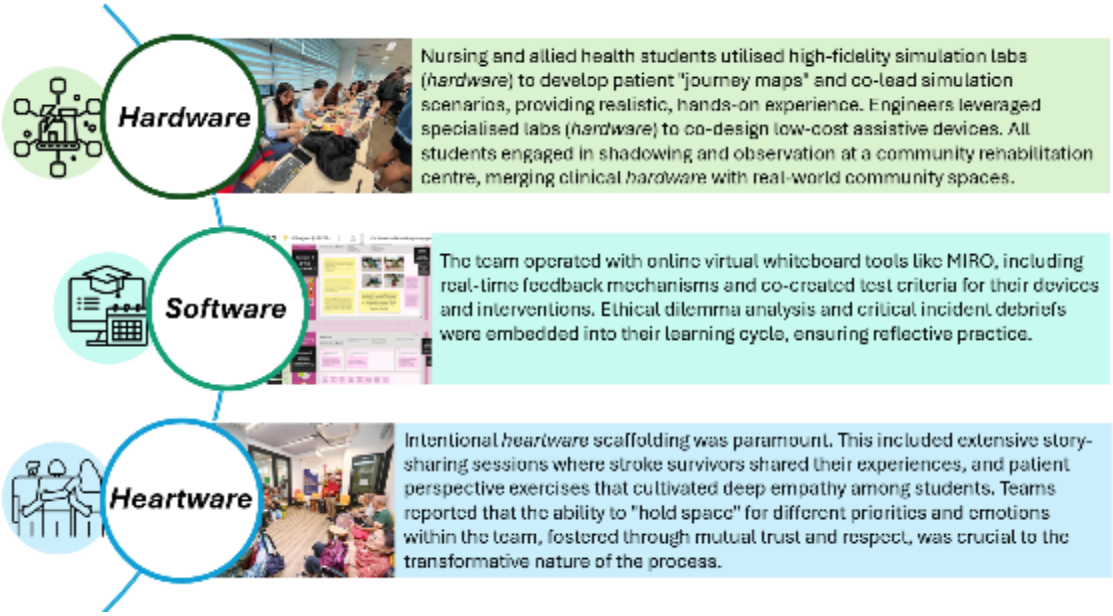
Findings

Based on the data collected, the H–S–H framework can be operationalised within SIT's Design Innovation module. The following vignette in Figure 7 illustrate the framework in

practice and they revealed how this integrated approach fosters deep interdisciplinary learning and prepares students for complex societal challenges.

A project team of students tackled the crucial area of rehabilitation for stroke survivors, integrating various disciplines and prioritising the human element (See Figure 8). Students engaged in high-fidelity simulations and community shadowing, co-designed affordable assistive devices, utilised digital collaboration platforms, and critically reflected on ethical dilemmas. Central to impact was empathetic engagement with stroke survivors, nurturing trust and shared responsibility for innovation.

Figure 7
A Vignette on Inclusive Healthcare



The collective data demonstrated several significant impacts:

- Increased Self-Efficacy and Interdisciplinary Comfort: Qualitative data, supported by module feedback surveys, showed statistically significant increases in student self-efficacy, their comfort with interdisciplinary collaboration, and cultural humility. This aligns with findings that PBL and SEL can lead to significant increases in student self-efficacy and a decrease in anxiety.
- Enhanced Project Creativity and Conflict Resolution: Teams that explicitly adopted *heartware* rituals and engaged in frequent reflection outperformed others in terms of project creativity, effective conflict resolution, and meaningful stakeholder engagement. This underscores *heartware* as both a multiplier and moderator in collaborative learning.
- Decreased Anxiety and Increased Group Identity: Module feedback reports a decrease in student anxiety and the willingness to think about their future, largely attributed to the introduction of the Designing your Life concepts. This aligns with literature showing that SEL enhances students' resilience, and with research indicating that PBL fosters a greater sense of ownership among students

These findings strongly affirm the H–S–H framework's ability to foster genuine interdisciplinarity, resilience, and compassion, producing graduates who are not only technically capable but also deeply empathetic and ethically grounded.

Discussion

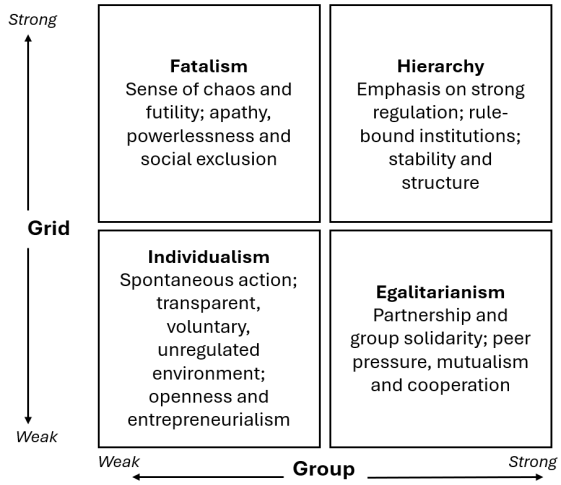
Based on the findings, a reflection was conducted on how the H–S–H framework, as conceptualised and operationalised at SIT where learning environments are designed at the intersection of space, process, and ethos, was able to empower educators to achieve their goals of enabling authentic interdisciplinarity and cultivate resilience in the face of complexity, while achieving the "buy-in" of students in the "wicked" context of diverse student learning preferences. To what extent the tri-layer framework which consciously aligns the components of physical infrastructure, curriculum, and community development (unlike traditional educational approaches that often treat them as distinct or siloed entities) for collective impact, enables measurable improvements in learning, innovation, and student well-being?

Deploying a Social Science Analytical Tool

While the findings from SIT's Design Innovation module resonate strongly with the global literature on applied learning, authentic assessment, and affective education, the reflection exercise required a more atypical analytical tool to sense-make the diversity in student learning preferences and how H-S-H aligns them to educators' goal of cultivating graduates who can lead, collaborate, and innovate across diverse professional, cultural, and technological landscapes. Such outcomes require students from diverse disciplinary cultures (how STEM students approach problem definition and solutioning is culturally distinct from students reading Business Management or Health Sciences) to learn about and experience the cultures of other disciplines. This is a complex endeavour that comes with challenges and even student resistance. Furthermore, an added complexity lies in the inherent diversity of learning preferences within each disciplinary cultures – as evident from past module feedback where students from the same disciplines expressed differing learning preferences. How may the H-S-H Framework empower SIT instructors to address these complexities? This salient reflection question needs to be addressed before the subsequent discussion on the transferability and scalability of the H-S-H Framework. First, this reflective exercise deployed Mary Douglas's Grid-Group Typology (1983, 2003) to sense-make the diversity in student learning preferences (see Figure 8).

Figure 8

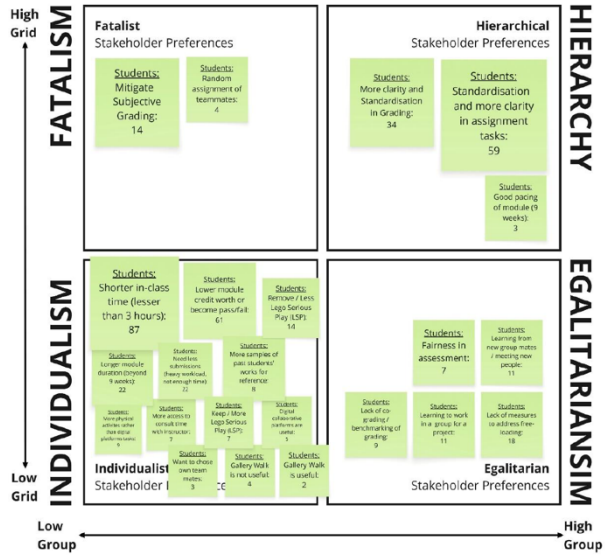
Mary Douglas's Grid-Group Typology Showing the Distinct Belief Systems of Each Rationality



Her groundbreaking typology helps to simplify the complexities of student learning preferences into just four mutually exclusive and jointly exhaustive rationalities based on their subscription to the criteria of Grid and Group: individualism, egalitarianism, hierarchism, and fatalism. Figure 8 below shows how Grid and Group can help reduce diverse preferences into the four rationalities with distinct belief systems. In the typology, *Grid* is characterized by the extent roles and rules influence a culture whereas *Group* is characterized by the extent group-orientation influence a culture. This simplification allows us to more reasonably sense-make the diversity of learning preferences by reducing its multitudes to more manageable parts for analysis. With this typology, the range of general student's learning preferences (as shared in the module feedback) can be mapped into the grid-group framework to provide an overview of the diversity of these preferences as shown in Figure 9 below. We further mapped the preferences particular to programme types into the typology to provide deeper insights.

Figure 9

Typology of Student's Learning Preferences for SIT's Design Innovation Module



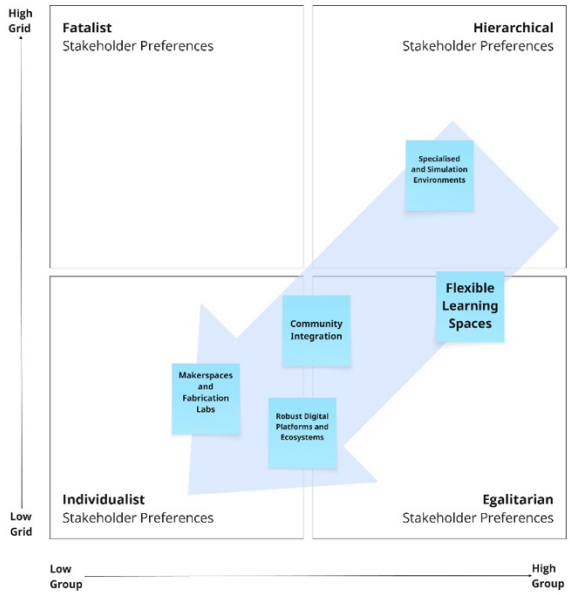
Second, this reflection exercise utilized a normative assertion, derived from cultural theory and its plural rationalities (Hartmann, 2012), building on Mary Douglas's Grid-Group Typology (1983, 2003) that posits that "wicked" problems need to be dealt pluralistically due to the diversity in belief-based preferences, and that the neglect of any of the three key rationalities of Hierarchy (H), Egalitarianism (E) or Individualism (I) will lead to gaps in outcomes. This assertion is used to derive our hypothesis that the H-S-H Framework empowered SIT instructors to achieve stated goals because the pluralism of the H-S-H Framework addressed the multitude of learning preferences – where the totality of implemented features catered to the learning preferences of students from all rationalities. To test the validity of this hypothesis, we mapped the range of implemented features onto the Grid-Group Typology to study if the H-S-H Framework is truly pluralistic. Our findings as presented below supports the hypothesis.

H-S-H as a Pluralistic Framework

The Hardware aspect of the framework caters to the three key rationalities of learning preferences (see Figure 10).

- Flexible Learning Spaces: The shift from rigid, siloed learning environments to collaborative, interactive spaces indicates a shift from “H” to “E” (Lowered Grid).
- Makerspaces and Fabrication Labs: Indicates a shift from “H” to “I” (rapid iteration) and “E” (cross-disciplinary projects) due to lowered Grid.
- Specialised and Simulation Environments: Retains the “H” (retaining emphasis of roles and rules).
- Community Integration: Catering to the “E” with equality of access to greenery and Community Park.
- Robust Sustainable Digital Platforms and Ecosystems: Catering to the “I” (technological enablers for individuals) and for “E” (co-located teamwork).

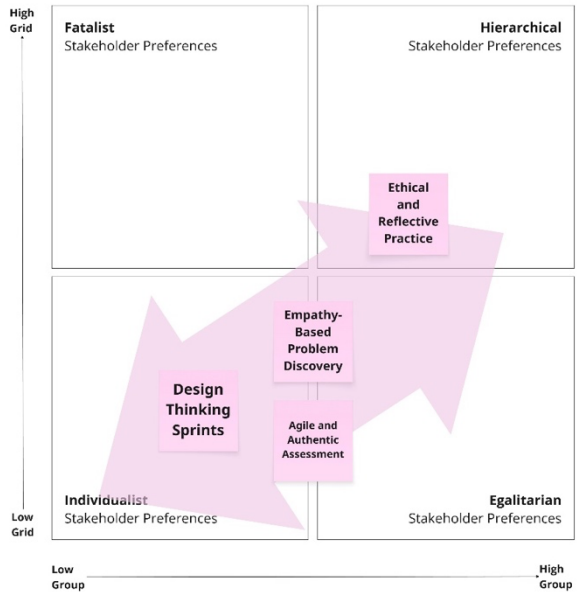
Figure 10
Typology of Hardware Implemented Features



The Software aspect of the framework also caters to the three key rationalities of learning preferences (see Figure 11).

- Empathy-Based Problem Discovery: Catering to the “E” (interviews with beneficiaries and stakeholders) and “I” (emphasising compassion)
- Design Thinking Sprints: Catering to the “I” (teaching them critical skills)
- Agile and Authentic Assessment: Catering to the “E” (peer feedback) and the “I” (reflective dialogue and removing rigid assessments)
- Ethical and Reflective Practice: Retaining the “H” (cultivating cultural ethical responsibility)

Figure 11
Typology of Software Implemented Features



Last but not least, the *Heartware* aspect of the framework also caters to the three key rationalities of learning preferences by cultivation of social capital (E), empathy (I), ethical reasoning (H), and a profound sense of ownership and care for both learning and community outcomes (E), on top of these pluralistic practices (as shown in Figure 12 below):

- Metacognitive Scaffolding: Caters to "I" (Designing your Life framework) and "E" (group check-ins and feedback).
- Inclusive Facilitation Framework: Caters to "I" (Professionals from various disciplinary backgrounds co-facilitate the module as instructors).
- Engagement and Storytelling: Caters to "E" (Project collaborations with diverse stakeholders) and "I" (open choice and authentic educator).

Figure 12
Typology of Heartware Implemented Features

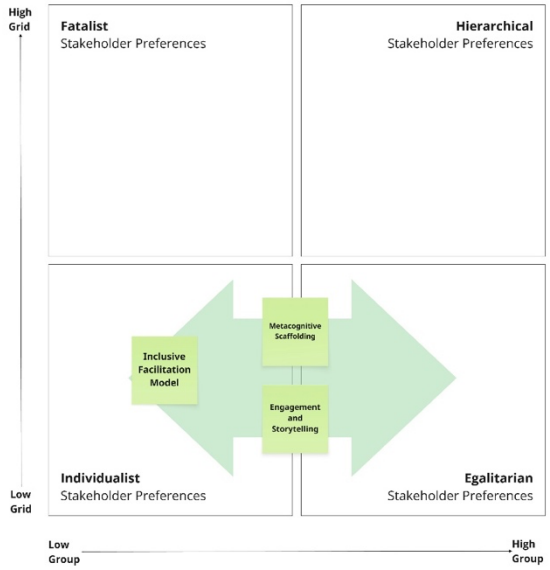
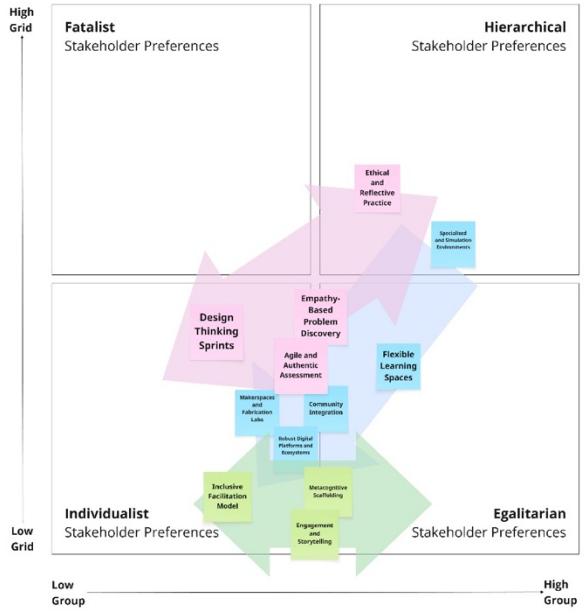


Figure 13 below illustrates the pluralism of the H-S-H Framework where the totality of implemented features catered to the learning preferences of students from all rationalities. Hence, we can posit with confidence that the H-S-H Framework which consciously aligns the components of physical infrastructure, curriculum, and community development for collective impact empowered the SIT instructors to achieve measurable improvements in learning, innovation, and student well-being; while also achieve their goals of enabling authentic interdisciplinarity for their students and cultivate in them the resilience needed in the face of complexity.

Figure 13
Typology of Totality of Implemented Features of H-S-H Framework



Structural and Cultural Enablers

Insights from the Grid–Group Typology highlight that the success and durability of the H–S–H framework at SIT depend on equally pluralistic enablers that mirror the pluralism of learner preferences. Institutional commitment functions as a hierarchical enabler: reconceiving the campus as a "living lab" and investing in flexible digital and physical infrastructure require leadership that emphasises the synergistic interplay of hardware, software, and heartware rather than isolated development.

At the individual level, comprehensive professional development equips faculty with both cognitive capabilities (e.g., interdisciplinary pedagogy, design thinking) and affective skills (e.g., *heartware* facilitation, conflict resolution, compassionate teaching), strengthening their capacity to enact the framework. Student ownership operates as both an individualist and egalitarian enabler, as autonomy, voice, and involvement in assessment design (such as co-created criteria) deepen engagement and motivation, particularly when learning is perceived as purposeful and choice-rich. Partnerships with external stakeholders, be it with industry (individualist) or community (egalitarian), are critical, providing authentic, socially meaningful projects that supply real-world problems, diverse perspectives, and relevance, while cultivating social responsibility and amplifying the framework's impact beyond the campus.

Barriers and Tensions

Insights from the Grid–Group Typology foreground the implementation and scaling challenges of the H–S–H framework by highlighting rationality-based conflicts in beliefs and preferences. Institutional inertia, rigid assessment structures, and resourcing constraints create hierarchical challenges that demand sustained effort, distributed leadership, and a willingness to "grapple with notions of impossibility" (Freeman et al., 2020, p. 86). Educators may also lack confidence or training in heartware facilitation, conflict resolution, and managing the emotional dynamics of interdisciplinary teamwork, underscoring the need for targeted support similar to that required for effective PBL design and scaffolding.

Assessment remains a persistent tension, as innovation is needed to balance individualist preferences for competition with egalitarian commitments to fairness and equality through methods that capture holistic learning beyond content mastery. Student adaptation to ambiguity presents another critical challenge: learners unfamiliar with open-ended, self-directed tasks may resist or feel discomfort, requiring "scaffolding for discomfort," explicit guidance, and hierarchical support to secure egalitarian group buy-in. The sustainability of H–S–H ultimately depends on institution-wide reinforcement, where its values are coherently embedded in recruitment, orientation, and co-curricular practices; misalignments across hardware, software, and ethos can significantly compromise outcomes.

Transferability of the Pluralistic H–S–H Framework

The mapping of the H–S–H framework onto the Grid–Group Typology suggests that, although rooted in Singapore's context, its pluralistic logic for addressing diverse learning preferences is broadly transferable across educational and societal settings. It can be modularised into general education to scaffold critical thinking, ethical imagination, and collaboration from the outset, preparing students for more complex interdisciplinary challenges. In industry–academia CET, real-world challenge-based modules, workplace learning, and mentorship can yield graduates with immediately applicable skills and holistic problem understanding.

Internationally, universities can adapt H–S–H by aligning *hardware* (campus and digital infrastructure), *software* (agile curricula), and *heartware* (socio-emotional and cultural practices) to local contexts, while investing in flexible, future-proof infrastructure that can accommodate emerging technologies such as AR and AI. Collaboration within and beyond institutions—with industry, tech firms, and other universities—supports trend sensing, guides infrastructural decisions, and enables interdisciplinary hubs, while environmental and social sustainability (e.g., green, inclusive spaces) ensures ongoing relevance.

Sustaining and scaling H–S–H depends on a strong culture of action research, including ongoing data collection, peer learning, pilots, and rigorous impact evaluation. Future research should examine longitudinal graduate outcomes (e.g., resilience, innovation, community orientation), develop robust ways to assess *heartware's* socio-emotional impacts, and pursue comparative studies across diverse systems to identify adaptation pathways and deepen efforts to humanise the academy amid accelerating change.

Conclusion

The Hardware–Software–Heartware (H–S–H) framework stands as a timely, evidence-driven response to the pressing need for reimagining how universities cultivate graduates equipped for civic contribution, professional leadership, and resilient innovation. By interrogating the intersecting roles of physical and digital infrastructure, curriculum design, and socio-emotional learning, this framework offers a comprehensive, pluralistic, and future-oriented lens on academic transformation. More importantly, the H–S–H framework demands that institutions invest not only in advanced facilities and adaptive curricula but, just as significantly, in the sustained and often unseen endeavour of nurturing empathy, ethical imagination, and a collective sense of purpose.

The experience at SIT underscores how intentional operationalisation of H–S–H catalyzes more than superficial interdisciplinarity or innovation as a rhetorical flourish; rather, it animates campus, curriculum, and community as synergistic spaces of authentic co-creation, visible societal impact, and enduring learning. Such integration is indispensable for understanding the ongoing infrastructural evolution within higher education, and it establishes a new world template for institutional research and policy reform.

In an era characterized by rapid complexity, digital disruption, and relentless change, integrated and pluralistic frameworks like H–S–H are not optional. They are essential for institutions determined to remain relevant, transformative, and genuinely future-ready. Ultimately, embracing the dynamic interplay of *hardware*, *software*, and *heartware* enables universities not only to adapt, but to lead; shaping a vision of education that realises humanity's full potential for compassion, creativity, and shared flourishing.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

The authors declare that Copilot, an AI-assisted writing software, was used in proofreading and refining the language used in the manuscript. The usage was limited to correcting grammatical and spelling errors and rephrasing statements for accuracy and clarity. The authors further declare that, apart from Copilot, no other AI or AI-assisted technologies have been used to generate content in writing the manuscript. The ideas, design, procedures, findings, analyses, and discussion are originally written and derived from careful and systematic conduct of the research.

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