

# Designing Engineering Curricula as Socio-Technical Systems: A Practice-Informed ST+EHoM Model

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## ABSTRACT

Electrical and electronic engineering graduates increasingly need to work with complex socio-technical systems involving technical, human, organisational, environmental and ethical dimensions. This creates a curriculum design challenge: programmes must develop technical depth while also helping students recognise interdependencies, frame problems, work with uncertainty, iterate solutions and adapt to changing constraints. This paper develops and illustrates a curriculum design process that combines systems thinking with Engineering Habits of Mind (EHoM). It argues that systems thinking can function both as a curriculum design logic and as an integrative engineering habit, while EHoM provides a language for translating this logic into learning outcomes, pedagogy, assessment and reflection. The paper adopts a practice-informed conceptual design case approach, drawing on the design and early implementation of an undergraduate engineering degree apprenticeship curriculum in a new higher education provider in England. The case is used to examine how the ST+EHoM model supported curriculum coherence, academic-workplace integration, assessment alignment and adaptive redesign, while also surfacing tensions around accreditation, staff capacity, student expectations and the balance between technical depth and disposition-oriented learning. The paper contributes a practical, conceptually grounded model for designing engineering curricula that prepare students to think and act as engineers within complex socio-technical systems.

## KEYWORDS

Engineering curriculum, curriculum design, systems thinking, Engineering Habits of Mind, socio-technical systems, degree apprenticeships

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## Introduction

Electrical and Electronics Engineering (EEE) graduates are increasingly expected to work with complex socio-technical systems. Contemporary engineering problems are shaped by interactions among technologies, users, organisations, regulation, environmental constraints, ethical responsibilities and economic pressures. In EEE contexts, technical decisions can have wider social, environmental and organisational consequences. Engineering education policy and accreditation frameworks therefore call for graduates who combine technical competence with systems awareness, ethical judgement, sustainability thinking, communication, teamwork and the ability to respond to

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uncertainty and change (Engineering Council, 2020; National Engineering Policy Centre, 2024, 2025; Royal Academy of Engineering, 2024).

This creates a curriculum design challenge. Engineering programmes must continue to develop disciplinary knowledge, mathematical capability and technical problem-solving skills. However, curricula organised around content, modular sequencing and well-structured problems may not give students enough opportunity to practise the judgement required in contemporary engineering practice. Students may learn to analyse circuits, model systems and apply technical principles, but have fewer structured opportunities to frame open-ended problems, interpret stakeholder needs, recognise interdependencies, evaluate trade-offs and improve solutions through feedback. Technical depth therefore needs to be developed within curricula that also cultivate professional formation, workplace relevance and adaptive engineering judgement (Beldad & Miedema, 2025; Passow & Passow, 2017; Sigahi et al., 2023).

Systems thinking offers one response. It foregrounds interdependence, feedback, boundaries, emergence, trade-offs, leverage points and adaptation, all central to engineering work in complex systems (Meadows, 2008; Monat et al., 2022). In engineering education, systems thinking is recognised as a capability needed by graduates who work across technical, social and organisational boundaries (Qadir et al., 2020; Royal Academy of Engineering, 2024). It is also relevant to curriculum design itself. A curriculum is not simply a sequence of modules, topics and assessments; it is an interconnected educational system shaped by outcomes, teaching, assessment, student expectations, staff expertise, institutional processes, accreditation, employer input and societal demands (Hicks, 2018; Rahdar et al., 2023; Spain, 2019).

However, systems thinking is often treated as a topic to be taught, a graduate capability to be developed, or a problem-solving technique used within modules. Less attention has been given to systems thinking as a curriculum design logic: a way of designing engineering curricula as adaptive socio-technical systems. Engineering Habits of Mind (EHoM) provide a complementary resource by describing engineering as cultivated dispositions associated with thinking and acting like an engineer: systems thinking, problem finding, creative problem solving, visualising, improving and adapting (Lucas et al., 2014). Their value lies in offering a discipline-specific language for engineering judgement that is often valued but not always explicitly designed for, taught or assessed.

Although systems thinking and EHoM are both relevant, their combined use as a curriculum design process remains underdeveloped. Systems thinking can help curriculum teams understand the curriculum as a socio-technical system, but may not provide a sufficiently discipline-specific language for engineering formation. EHoM can make engineering dispositions visible, but without a systems-oriented design logic they risk becoming another list of attributes mapped onto a crowded curriculum. The gap addressed in this paper is therefore the absence of a clear process combining systems thinking as design logic with EHoM as a language for engineering dispositions.

This paper develops and illustrates such a process. It proposes an ST+EHoM curriculum design model for undergraduate engineering education, with particular relevance to EEE curricula. Systems thinking functions as a curriculum design logic, helping teams define the curriculum system, map stakeholders, align learning and assessment, and build feedback loops. It is also positioned as both one Engineering Habit of Mind and an integrative meta-habit connecting problem finding, creative problem solving, visualising, improving and adapting. EHoM provide the language through which this systems orientation is translated into outcomes, pedagogy, assessment and reflection.

The paper adopts a practice-informed conceptual design case approach, developing the model conceptually and illustrating its application through the design and early implementation of an undergraduate engineering degree apprenticeship curriculum in a new higher education provider in England. The case is not a formal evaluation of student outcomes, but an analytically generative

example of curriculum development linking academic learning, workplace practice, employer expectations, accreditation and student identity formation.

The paper makes three contributions: it reframes engineering curriculum design as a socio-technical systems challenge; develops an ST+EHoM model combining systems thinking with engineering dispositions; and illustrates how this model can support curriculum coherence, academic-workplace integration, assessment alignment and adaptive redesign, while surfacing tensions around regulation, capacity, expectations and technical depth.

## Literature and conceptual foundations

### *Engineering curriculum design as a socio-technical challenge*

Engineering curriculum design is being reconsidered in response to changes in engineering practice. Engineers are expected not only to apply disciplinary knowledge, but also to work with complex systems involving social, technical, environmental, economic and ethical dimensions. This is especially significant in electrical and electronic engineering, where graduates may work on energy systems, communications infrastructure, embedded systems, robotics, automation, sensing technologies, cyber-physical systems and intelligent devices. In these contexts, technical decisions are rarely separate from questions of safety, sustainability, regulation, user behaviour, organisational practice and societal consequence.

This shift has implications for curriculum design. Traditional engineering curricula have often been organised around disciplinary sequencing, mathematical and scientific foundations, technical analysis and the progressive accumulation of specialist knowledge. These remain essential. However, they are not sufficient if graduates are to work effectively with open-ended socio-technical problems. Curricula that prioritise technical content without also designing for problem framing, stakeholder reasoning, ethical judgement, interdisciplinarity and adaptation risk preparing students for well-structured academic tasks rather than the more ambiguous problems of engineering practice (Beldad & Miedema, 2025; Passow & Passow, 2017; Sigahi et al., 2023).

The need for broader capability is reflected in accreditation and policy frameworks. AHEP4 places increased emphasis on sustainability, ethics, inclusive design, security, professional responsibility and the wider societal impact of engineering activity (Engineering Council, 2020). Recent Royal Academy of Engineering and National Engineering Policy Centre work similarly argues that future engineers need technical competence alongside systems awareness, creativity, judgement, communication and the ability to work across boundaries (National Engineering Policy Centre, 2024, 2025; Royal Academy of Engineering, 2024). These developments do not displace technical depth; they require curricula to connect technical knowledge more deliberately with professional formation and socio-technical reasoning.

Curriculum design is therefore itself a socio-technical challenge. Decisions are shaped by disciplinary content, institutional structures, accreditation, staff capacity, assessment regimes, employer input, workplace practices and student expectations. As Kolmos et al. (2016) argue, transformative curriculum change requires more than adding new content; it involves rethinking the purposes, relationships and pedagogical arrangements through which students learn. The challenge is to design curricula that connect technical learning with authentic problems, stakeholder contexts and professional practice coherently, rather than leaving socio-technical learning to emerge incidentally (Linville et al., 2026).

### ***Systems thinking in curriculum design***

Systems thinking provides a useful conceptual resource for this challenge because it directs attention to relationships, feedback, boundaries, emergence and adaptation. Meadows (2008, p. 11) defines a system as “an interconnected set of elements that is coherently organized in a way that achieves something”. Applied to curriculum design, this shifts attention from individual components to the relationships among them. Modules, learning outcomes, assessment tasks, staff practices, student expectations, employer requirements and accreditation standards interact to shape the student learning experience and the forms of engineering capability that are developed.

In engineering education, systems thinking is often justified by the complexity of engineering practice. Monat et al. (2022) argue that undergraduate engineering education should develop students’ capacity to understand interconnections, complex interactions, feedback and holism. Qadir et al. (2020) similarly identify systems thinking as an important capability for electrical and computer engineers working in rapidly changing technological and societal contexts. This is especially relevant to EEE, where students need to understand interactions among components, devices, users, networks, infrastructures, software, data, organisations and environments.

Systems thinking also has value as a curriculum design approach. In higher education, it has been used to understand curricula as complex adaptive systems shaped by multiple internal and external influences (Rahdar et al., 2023; Spain, 2019). It can help curriculum teams move beyond linear planning models and attend to system boundaries, stakeholder relationships, feedback loops and leverage points. This is significant because engineering curricula often generate unintended consequences (Doorsamy, 2025). Assessment designed to assure technical competence may encourage procedural correctness over exploratory problem framing. Project-based learning may fail to promote creativity if students lack scaffolding or if assessment rewards final products more than engineering reasoning. Workplace learning may remain peripheral if it is not connected to academic outcomes and reflection. Systems thinking helps curriculum teams anticipate such relationships and makes curriculum development more adaptive. However, it does not by itself specify the engineering dispositions students should develop. This is where EHoM become important.

### ***Engineering Habits of Mind and engineering dispositions***

Engineering Habits of Mind provide a complementary framework because they describe engineering as a set of cultivated dispositions, rather than only as a body of knowledge. The Royal Academy of Engineering’s Thinking Like an Engineer report identifies six EHoM: systems thinking, adapting, problem finding, creative problem solving, visualising and improving (Lucas et al., 2014). These habits describe characteristic ways in which engineers approach problems, make judgements and act under uncertainty and constraint. They therefore offer a discipline-specific language for capabilities often described more generally as transferable skills, professional skills or employability.

The concept of habits of mind is useful because it foregrounds dispositions. Dispositions are not simply skills demonstrated once; they are patterned ways of thinking and acting that develop through repeated practice, reflection and feedback (Costa & Kallick, 2000). In engineering education, this distinction matters. Students may know how to apply a technical method in a defined context, but still need to develop the judgement to decide when that method is appropriate, how a problem should be framed, what trade-offs matter, and how designs should be improved or adapted. EHoM help make these forms of judgement visible within curriculum design.

EHoM also connect technical learning with engineering identity. Students do not become engineers only by accumulating disciplinary knowledge. They learn to participate in engineering practices,

reason with uncertainty, respond to failure, visualise possibilities, iterate solutions and recognise the wider consequences of technical decisions. Research on engineering identity shows that students' sense of becoming an engineer is shaped by how they encounter and participate in valued engineering practices (Claussen et al., 2023).

The framework is particularly relevant to project-based, design-based and workplace-integrated curricula. These approaches give students opportunities to encounter open-ended problems, test solutions and reflect on decisions. However, such opportunities do not automatically develop engineering dispositions. Without explicit framing, students may experience projects mainly as tasks to complete. EHoM can therefore help curriculum teams design learning, assessment and reflection so that engineering habits are introduced, practised, evidenced and transferred across academic and workplace contexts.

### ***From existing approaches to an integrated curriculum design model***

Existing curriculum design approaches offer important resources but do not fully address the problem developed above. Constructive alignment connects intended learning outcomes, teaching activities and assessment tasks (Biggs & Tang, 2011). CDIO situates disciplinary knowledge alongside personal, interpersonal and system-building skills within the lifecycle of engineering practice (Crawley et al., 2014). Project-based and challenge-based learning give students opportunities to engage with authentic problems and integrate knowledge across domains (Doulougeri et al., 2024; Mitchell et al., 2021). The model developed in this paper is therefore complementary to these approaches, rather than a replacement.

However, three limitations remain significant for EEE curriculum design. First, existing approaches do not always make the curriculum itself visible as a socio-technical system. Constructive alignment can work well at module level without addressing wider stakeholder relationships, workplace learning, accreditation pressures, institutional constraints or feedback loops. CDIO provides a broader engineering education architecture, but its adoption does not automatically foreground systems thinking as a curriculum design logic.

Second, systems-thinking approaches to curriculum design are often generic rather than discipline-specific. They offer useful concepts such as boundaries, interdependencies, feedback loops and leverage points (Rahdar et al., 2023; Spain, 2019) but do not necessarily explain what it means for students to develop specifically engineering ways of thinking. This is important in EEE because systems-level awareness must be connected to technical practices such as modelling, circuit analysis, signal processing, embedded design, control, testing, troubleshooting and system integration.

Third, existing approaches can leave unresolved the relationship between technical depth and professional formation. Engineering educators are often asked to preserve disciplinary rigour while also addressing sustainability, ethics, teamwork, communication, interdisciplinarity and workplace readiness. If these broader capabilities are not integrated through a coherent design logic, they can appear as add-ons or competitors to technical content, especially in dense and sequential EEE curricula.

These limitations suggest the need for a curriculum design approach that works at two connected levels. At the curriculum-system level, systems thinking can help educators define purpose and boundaries, map stakeholders, examine relationships among curriculum components, identify feedback loops and recognise implementation constraints. At the student-development level, EHoM can specify what students are being formed to do and become. The model developed in this paper brings these levels together by combining systems thinking as a curriculum design logic with EHoM

as a language for engineering formation. The next section explains how this model was developed and applied through a practice-informed conceptual design case.

## Methodological approach

### *Research design*

This paper adopts a practice-informed conceptual design case approach. Its purpose is to develop and illustrate a curriculum design model that combines systems thinking and EHoM and to examine what becomes visible when the model is applied in the design and early implementation of an undergraduate engineering curriculum.

This approach is appropriate because the paper addresses a design problem: how engineering curricula can support technical depth, systems thinking, professional formation and adaptive judgement. Conceptual papers are useful when they clarify constructs, connect bodies of literature and propose new ways of addressing a problem (Jaakkola, 2020). Here, the conceptual work brings together systems thinking as a curriculum design logic and EHoM as a language for engineering dispositions, a relationship previously untested in engineering curriculum design.

The case element allows the model to be examined in a real curriculum design setting. Case study approaches are useful for analysing complex phenomena where context is integral to what is being studied (Yin, 2018). Curriculum design is shaped by institutional structures, accreditation requirements, employer expectations, staff capacity, assessment regimes and student experience. The case therefore provides an analytically generative setting for exploring how the ST+EHoM model operates in practice. The aim is analytical insight rather than statistical generalisation (Flyvbjerg, 2006; Yin, 2018).

Although the study has affinities with educational design research, it does not claim to be a full design-based research study involving formal cycles of intervention, data collection and evaluation (McKenney & Reeves, 2019). Instead, it uses curriculum development activity as the basis for conceptual model-building and early-stage analytical reflection.

### *Case context and model development*

The case is the design and early implementation of an undergraduate engineering degree apprenticeship curriculum in a new higher education provider in England. The Dyson Institute of Engineering and Technology was established as a new HE institution specifically to cultivate the innovative type of engineer required by its founding employer, Sir James Dyson (Emms et al., 2021). The institution has been pioneering a new model of engineering higher education that integrates innovative academic programmes with hands-on work on live engineering projects (Dyson Institute of Engineering and Technology, 2023). The programme was designed to connect academic learning, workplace practice, professional behaviours, assessment requirements and accreditation expectations. Although not a conventional single-discipline EEE degree, the curriculum included substantial EEE-related learning and design activity, including systems, circuits, modelling, embedded technologies, technical problem solving and workplace-based engineering practice.

The case was selected because degree apprenticeships require coordination among providers, employers, apprentices and workplace mentors, and explicitly combine academic study with employment-based learning (Laczik et al., 2024). Students are positioned both as learners and employees, requiring curriculum design to account for formal educational progression and workplace performance. In this case, as Dyson employees, students were working as engineers from day one,

applying engineering concepts to real-life problems in workplace projects led by Dyson engineers, who were normally the students' line managers. Some Dyson engineers also had the role of workplace mentor for students. Although the new-provider context offered scope for curriculum rebuilding, it still had to operate within quality assurance, apprenticeship, employer and accreditation constraints.

The ST+EHoM model was developed through conceptual synthesis and curriculum design application. The synthesis drew on systems thinking, which emphasises interdependence, feedback, boundaries, emergence, leverage points and adaptation (Meadows, 2008; Monat et al., 2022; Stroh, 2015), and EHoM, which describes engineering as cultivated dispositions, including systems thinking, problem finding, creative problem solving, visualising, improving and adapting (Lucas et al., 2014).

The model was developed by asking how these frameworks could perform complementary roles. Systems thinking framed the curriculum as a socio-technical system, directing attention to relationships among curriculum intent, technical content, pedagogy, assessment, workplace learning, stakeholder input, accreditation and feedback. EHoM articulated the forms of engineering judgement and action the curriculum sought to cultivate.

### ***Sources of practice insight and analytical approach***

The analysis draws on practice insights generated during design and early delivery. These included programme planning, module design documentation, learning outcomes, project briefs, assessment design, reflective tasks, stakeholder discussions, teaching-team reflection, informal student feedback, workplace-facing feedback and observations of early implementation issues.

These sources illuminated how the curriculum was conceptualised, how the ST+EHoM model informed design decisions, and what tensions emerged. Programme and module documentation showed how curriculum intent was translated into outcomes, teaching activities and assessment. Assessment briefs and reflective tasks indicated how engineering dispositions were made visible. Stakeholder discussions clarified how academic, workplace and employer perspectives shaped the curriculum. Feedback from students, staff and workplace-facing stakeholders identified where scaffolding or redesign was needed.

These sources were not treated as a formal empirical dataset based on systematic sampling, interviews, surveys or outcome measures. Instead, they were used as situated design evidence generated through curriculum development and early implementation. The paper therefore does not measure student learning gains or curriculum effectiveness. It analyses how the ST+EHoM model functioned as a design process and what it revealed about affordances, challenges and future development needs.

The analysis was guided by the ST+EHoM model. Systems thinking was used to examine curriculum purpose, boundaries, stakeholders, interdependencies, feedback loops, constraints and adaptation. EHoM were used to examine how engineering dispositions were cultivated through outcomes, project activity, assessment and reflection.

### ***Positionality and limitations***

The first author's direct involvement in the curriculum design process provided insider access to the design rationale, stakeholder interactions and implementation tensions. Insider research can generate rich contextual understanding, particularly where the phenomenon involves organisational and professional practice (Coghlan & Brannick, 2014; Schön, 1983). However, it also creates risks of selective interpretation and confirmation bias. Claims are therefore framed as practice-informed insights rather than independently verified empirical findings.

The case is contextually bounded. It is drawn from a single new higher education provider and a degree apprenticeship with close employer involvement. The model should therefore be read not as a directly

transferable template, but as a design logic and set of analytical questions that can be adapted to other EEE and engineering education contexts.

## Development of the ST+EHoM model

### *Model purpose and design logic*

The ST+EHoM model is a curriculum design process that combines systems thinking with EHoM. Its purpose is to help engineering educators design curricula that preserve technical depth while also cultivating the dispositions students need to think and act as engineers in complex socio-technical contexts. The model responds to the problem established in the preceding sections: EEE curricula need to support technical knowledge while also enabling students to frame open-ended problems, reason across systems, interpret stakeholder needs, evaluate trade-offs, respond to feedback and adapt to changing constraints.

The model brings together two complementary resources. Systems thinking provides the curriculum design logic. It helps curriculum teams understand the curriculum as an interconnected system involving students, staff, learning outcomes, assessment, workplace learning, accreditation requirements, employer expectations, institutional processes and wider societal needs. This draws on systems thinking concepts such as purpose, boundaries, interdependence, feedback, emergence, leverage points and adaptation (Meadows, 2008; Monat et al., 2022; Stroh, 2015). EHoM provide the language of engineering formation by identifying the dispositions students need to practise and develop: systems thinking, problem finding, creative problem solving, visualising, improving and adapting (Lucas et al., 2014).

The model therefore operates at two connected levels. At the curriculum-system level, it asks how the curriculum is designed, aligned, experienced and improved. At the student-development level, it asks how students are supported to develop engineering ways of thinking through repeated practice, feedback, assessment and reflection. Its value lies in connecting these levels: systems thinking is used to design the curriculum as a socio-technical system, while EHoM specify the forms of engineering judgement the curriculum seeks to cultivate.

### *The six-stage design process*

The ST+EHoM model is organised around six iterative stages. These are presented sequentially for clarity, but curriculum teams may move back and forth between them as new evidence, constraints or stakeholder perspectives emerge. This reflects the view of curriculum design as adaptive and situated, rather than as a one-off planning exercise (Rahdar et al., 2023; Spain, 2019).

The first stage is to define the curriculum system. This involves clarifying the purpose and boundaries of the curriculum: what kind of engineering graduate the programme seeks to develop, what technical and professional capabilities are required, and what institutional, disciplinary, workplace and regulatory contexts shape the curriculum. Decisions about whether the curriculum system includes workplace learning, employer input, accreditation expectations or professional identity formation influence what is designed and what may be overlooked.

The second stage is to map stakeholders, relationships and constraints. Engineering curricula are shaped by students, academic staff, technicians, workplace engineers/mentors, employers, alumni, professional bodies, accreditation panels, institutional leaders and external partners. Mapping these relationships helps identify where alignment is needed, where tensions may arise and where feedback loops can support improvement. This stage draws directly on systems thinking's concern with interdependence, feedback and leverage points (Meadows, 2008; Stroh, 2015).

The third stage is to identify the intended engineering dispositions. Rather than treating professional capability as a generic list of transferable skills, this stage asks what it means for students in a specific engineering context to practise systems thinking, problem finding, creative problem solving, visualising, improving and adapting. It links curriculum purpose to student formation and avoids assuming that such dispositions will emerge automatically from technical content, laboratory work or project activity.

The fourth stage is to design learning activities and curriculum experiences. These may include project-based tasks, design challenges, laboratory work, modelling activity, workplace problems, simulations, design reviews, stakeholder engagement, reflective activities and interdisciplinary projects. The key question is whether activities give students repeated opportunities to use technical knowledge while practising the intended habits of mind.

The fifth stage is to align assessment, feedback and reflection. If EHoM are to shape student learning, they need to be visible in assessment criteria, feedback processes and reflective tasks. This does not require assessing dispositions separately from technical learning. Rather, assessment should enable students to demonstrate engineering judgement through technical work: how they framed a problem, represented a system, interpreted stakeholder requirements, justified decisions, responded to feedback, improved a design or adapted to unexpected results. This extends constructive alignment by treating engineering dispositions as assessable dimensions of professional formation (Biggs & Tang, 2011; Lucas et al., 2014).

The sixth stage is to build adaptive feedback and redesign loops. Feedback may come from students, staff, workplace engineers/mentors, employers, assessment outcomes, external examiners, accreditation processes, graduate data and programme review. The model asks not only whether feedback is collected, but how it is used to adjust curriculum design. This is especially important in EEE, where curricula must respond to changing technologies, professional practices, sustainability demands, regulatory expectations and student needs.

### ***Roles of systems thinking and EHoM in the model***

Systems thinking performs three functions in the model. First, it conceptualises the curriculum as an interconnected educational system. This shifts attention away from content coverage or module sequencing alone and towards relationships among curriculum intent, learning activities, assessment, student experience, stakeholder input, professional expectations and graduate outcomes. This is consistent with systems-informed approaches that understand curricula as complex systems shaped by interacting internal and external influences (Hicks, 2018; Rahdar et al., 2023; Spain, 2019).

Second, systems thinking has a diagnostic function. It helps curriculum teams identify where alignment is strong, where fragmentation exists and where unintended consequences may arise. A curriculum may claim to value creativity and adaptation, for example, while assessment criteria reward technical correctness and procedural certainty. A programme may emphasise workplace relevance, while workplace learning remains weakly connected to academic assessment or reflection. Systems thinking helps make such misalignments visible.

Third, systems thinking has an adaptive function. It supports feedback loops through which the curriculum can learn from implementation. Engineering curricula operate in changing environments: accreditation expectations evolve, technologies develop, employer needs shift, student cohorts change and institutional constraints emerge. A systems-informed model therefore treats redesign as a normal feature of curriculum work, rather than as an exceptional response to failure.

EHoM perform a different but complementary role. They provide the language of student formation. Whereas systems thinking helps curriculum teams understand and design the curriculum system, EHoM specify the forms of engineering judgement students should develop within that system. This is significant because terms such as employability, transferable skills or graduate attributes can appear generic or detached from engineering practice. EHoM are more discipline-specific: they describe how engineers identify and frame problems, reason systemically, visualise possibilities, generate solutions, improve designs and adapt to changing constraints (Lucas et al., 2014). They also align with graduate dispositions sought by engineering employers (Linville et al. 2026)

In curriculum design, EHoM can inform learning outcomes, guide activity design, shape assessment criteria and support reflection. They help educators ask whether students have repeated opportunities to practise engineering judgement and whether that judgement is recognised in feedback and assessment. This dispositional focus draws on wider work on habits of mind, which emphasises repeated practice, reflection and feedback as the basis for developing patterned ways of thinking and acting (Costa & Kallick, 2000). It also aligns with engineering education research on design thinking and professional formation, which highlights problem framing, iteration, modelling, decision-making and judgement as central to engineering learning (Dym et al., 2005; Passow & Passow, 2017).

### *Systems thinking as habit and meta-habit*

A distinctive feature of the ST+EHoM model is the dual positioning of systems thinking. In the original EHoM framework, systems thinking is one of six EHoM, alongside problem finding, creative problem solving, visualising, improving and adapting (Lucas et al., 2014). In this model, systems thinking remains one habit among the six, but is also positioned as an integrative meta-habit (Figure 1).

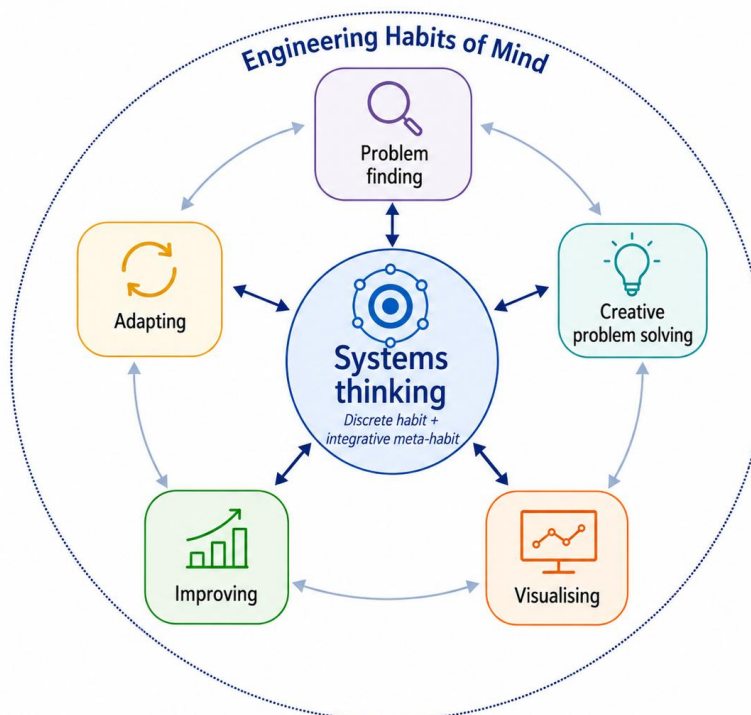


Figure 1. Systems thinking as one of the six Engineering Habits of Mind and as an integrative meta-habit connecting the other five within the ST+EHoM curriculum design model

This does not mean that systems thinking replaces the other habits or is more important than them. Rather, it provides a connective logic that strengthens how the other habits are understood and practised. Engineering problems are rarely isolated. They are situated within systems of stakeholders, materials, technologies, organisations, environments, regulations and consequences. For this reason, problem finding, creative problem solving, visualising, improving and adapting become more powerful when practised systemically.

Problem finding requires students to consider how a problem has been framed, whose perspectives are included or excluded, and what assumptions define the problem boundary. Creative problem solving becomes more responsible when solutions are evaluated in relation to sustainability, safety, usability, maintainability, ethics and organisational fit. Visualising extends beyond diagrams of components to include relationships, feedback loops, dependencies, system behaviours and trade-offs. Improving becomes more than local optimisation when students consider the purpose and performance of the whole system. Adapting involves purposeful response to feedback, uncertainty and changing constraints.

Positioning systems thinking as a meta-habit is therefore both analytical and pedagogical. It clarifies how the other EHoM can be cultivated in ways that respond to socio-technical complexity. It also helps educators connect learning outcomes, activities, assessment and feedback around a shared concern with interdependence, trade-offs and adaptation. The next section illustrates how this model was applied in the curriculum case.

### **Application of the model to the curriculum**

This section illustrates how the ST+EHoM model was applied to the design and early implementation of the engineering degree apprenticeship curriculum. The aim is not to evaluate student outcomes, but to show how the model operated as a practical curriculum design process (Figure 2). The case material draws on programme and module documentation, assessment design, stakeholder discussions, teaching-team reflection, informal student and workplace-facing feedback, and early implementation adjustments.

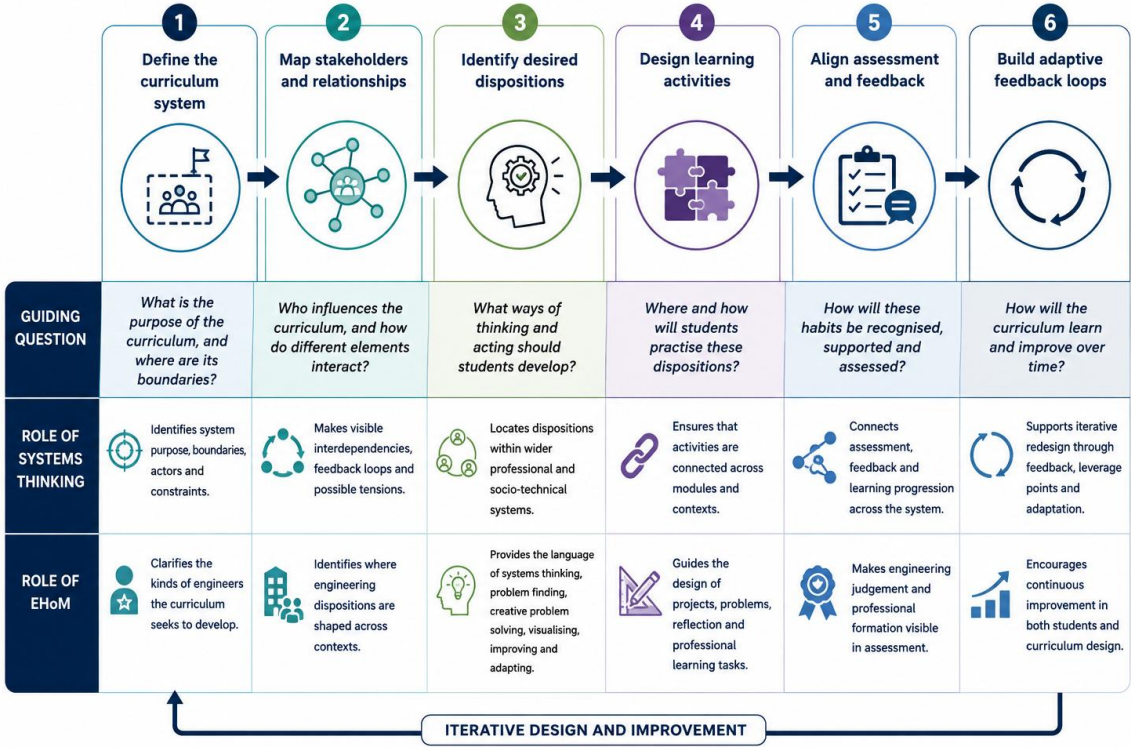


Figure 2. The ST+EHoM curriculum design process: design stages, guiding questions and framework functions

Defining the curriculum system

The first stage was to define the curriculum as a socio-technical system rather than as a sequence of modules. This was particularly important because the programme was a degree apprenticeship: students were both higher education learners and employees developing professional capability in an engineering workplace. Degree apprenticeships require integration between academic study, workplace learning, employer expectations and assessment requirements (Laczik et al., 2024).

The curriculum system was defined around the purpose of developing emerging engineers who could combine technical depth with systems awareness, professional judgement and adaptive problem solving. In EEE-related contexts, this meant more than covering circuits, systems, modelling, embedded technologies and design. It also meant asking how students would learn to understand interactions among technical components, users, workplace constraints, safety considerations, sustainability implications and organisational requirements. This reflects the broader need for engineering curricula to prepare students for socio-technical complexity rather than only well-structured technical problems (Monat et al., 2022; Qadir et al., 2020; Sigahi et al., 2023).

The curriculum boundary was therefore expanded beyond scheduled teaching and formal assessment. It included pre-induction and induction activity, technical modules, project-based learning, laboratory work, workplace activity, mentoring conversations, reflective tasks, apprenticeship evidence, feedback processes and programme review. This mattered because engineering dispositions and identity formation developed across multiple settings rather than within a single module. Systems thinking helped make these relationships visible by directing attention to boundaries, interdependencies, feedback and adaptation (Meadows, 2008; Spain, 2019; Stroh, 2015).

A practical consequence was that design work began from the question: what kind of engineer is this curriculum trying to develop? This shifted attention away from content coverage alone and towards a connected learning system in which technical learning remained central, but was linked to judgement, responsiveness and professional capability.

### ***Mapping stakeholders and boundaries***

The second stage was to map the stakeholders, relationships and constraints shaping the curriculum. The degree apprenticeship involved students, academic staff, workplace engineers/mentors, institutional leaders, employer representatives, alumni, external employers, professional bodies, accreditation stakeholders and higher education advisors. Each group influenced the curriculum differently: academic staff brought disciplinary and pedagogical expertise; Dyson engineers brought insight into professional practice; additional university leaders and external EE employers contributed expectations about workplace readiness; and students provided feedback on how the curriculum was experienced.

Mapping these stakeholders helped identify the curriculum as a boundary-crossing system. Students moved between co-located academic and workplace settings, and the curriculum needed to support that movement. Workplace engineers/mentors were important because they could help students connect module learning with workplace practice. Assessment briefs, reflective portfolios, project artefacts and mentor discussions functioned as boundary objects, helping students, academic staff and workplace stakeholders coordinate around shared evidence of learning while retaining different perspectives (Akkerman & Bakker, 2011; Star & Griesemer, 1989).

The mapping process also highlighted potential misalignments. Academic staff might value conceptual understanding and reflective development, while students might prioritise assessment performance or technical correctness. Workplace stakeholders might expect practical readiness, while higher education quality processes require evidence of academic progression, assessment validity and level-appropriate learning. Accreditation and apprenticeship requirements introduced further expectations that had to be translated into curriculum structures and assessment evidence. Such tensions are common in professional and work-integrated curricula, where learning is distributed across educational and workplace systems (Billett, 2009; Lester & Bravenboer, 2020).

### ***Translating EHoM into learning outcomes and activities***

Having identified EHoM at the third stage as the desired engineering dispositions, the fourth stage was to translate EHoM into learning outcomes, pedagogical activities and curriculum experiences. EHoM provided a discipline-specific language for the forms of thinking and acting the curriculum sought to cultivate: systems thinking, problem finding, creative problem solving, visualising, improving and adapting (Lucas et al., 2014). The intention was not to add a separate “habits” strand, but to embed these dispositions within technical learning, project work, workplace reflection and assessment.

At programme level, EHoM helped clarify the developmental journey expected of students. Students were introduced to engineering identity and mindset during early engagement, pre-induction and induction activities. The habits were then revisited through technical modules, project-based learning, assessment tasks and workplace-facing reflection. This reflected the view that dispositions develop through repeated practice, feedback and reflection rather than one-off instruction (Costa & Kallick, 2000).

At module level, EHoM were translated into activities requiring students to use technical knowledge in open-ended ways. One example was a project-based fire alarm system design activity. Students worked with voltage thresholds, circuit behaviour, signal reliability and noise filtering, but the task was also framed through wider system considerations such as user behaviour, manufacturing feasibility, sustainability, reliability and consequences of failure. This allowed the activity to function as a socio-technical design task rather than simply a technical exercise.

The fire alarm activity enabled several habits to be practised together. Students engaged in problem finding by interpreting the design need and identifying constraints. They used systems thinking by considering interactions among components, users, environments and reliability requirements. They practised visualising through circuit diagrams, simulations and representations of system behaviour. They developed creative problem solving by considering alternatives, improving through testing and iterative refinement, and adapting when results did not match expectations or constraints changed. This reflects wider arguments that project-based and design-based learning are strongest when students engage in authentic engineering reasoning rather than merely complete a product (Dym et al., 2005; Kolmos et al., 2016; Mitchell et al., 2021).

EHoM also supported students' reflective understanding of their development. The T-shaped professional model was used to connect disciplinary depth with broader professional capability, helping students see professional formation not as a substitute for technical expertise, but as the capacity to use technical expertise effectively in wider contexts (Passow & Passow, 2017; Rogers & Freuler, 2015).

### ***Aligning assessment and feedback***

The fifth stage was to align assessment and feedback with the intended engineering dispositions. This was essential because dispositions are unlikely to shape student learning if they remain absent from assessment. Constructive alignment emphasises the connection between intended learning outcomes, teaching activities and assessment tasks (Biggs & Tang, 2011). The ST+EHoM model extends this by asking how assessment can recognise not only technical outputs, but also engineering judgement, iteration, reflection and adaptation.

Assessment therefore drew on multiple forms of evidence. Technical tasks assessed disciplinary understanding and application of engineering principles. Project work assessed design reasoning, system integration and decision-making under constraint. Reflective reports asked students to explain how they approached problems, responded to feedback and connected academic learning with workplace practice. Team presentations required students to communicate design choices and justify trade-offs. Individual vivas probed understanding, decision-making and ownership of work. Workplace-facing evidence connected academic activity with professional practice.

This assessment ecology mattered because no single format could capture the full range of intended outcomes. Written assessments could evidence analytical competence, but were less suited to adaptation, reflection or workplace judgement. Group project outputs could show design performance, but needed individual reflection or viva components to make students' reasoning visible. Workplace evidence could demonstrate professional relevance, but required academic framing to ensure that learning was critically interpreted rather than simply described.

Feedback was also treated as part of the curriculum system. Formative feedback through laboratories, project activity, design discussions, peer review and teaching-team interaction was used not only to correct errors, but to support students in improving their engineering reasoning. This aligns with feedback literature that positions feedback as a process through which learners develop evaluative

judgement and improve future work (Boud & Molloy, 2013; Hattie & Timperley, 2007; Sadler, 1989). In the fire alarm project, for example, feedback addressed not only whether circuit behaviour met the required threshold, but also how students justified design choices, represented system relationships, tested alternatives and responded to unexpected results.

### ***Building adaptive redesign loops***

The sixth stage was to build adaptive redesign loops into the curriculum. Systems thinking treats feedback as central to how systems change and improve (Meadows, 2008; Stroh, 2015). Applied to curriculum design, this means that implementation evidence should inform redesign rather than function only as post-delivery evaluation. This was particularly important in a new provider and degree apprenticeship context, where academic and workplace expectations needed continual calibration.

During early implementation, feedback from students, workplace-facing stakeholders and teaching staff identified areas where the curriculum required further scaffolding. One example concerned students' difficulty connecting theoretical circuit analysis with practical system design. In response, the teaching team introduced additional formative activities, including peer walkthroughs and design sprints. These gave students structured opportunities to explain assumptions, visualise circuit behaviour, discuss alternatives, identify sources of error and connect theory with practical implementation. This illustrates the adaptive function of the model: implementation feedback was used to strengthen the relationship between technical learning and engineering habits.

The redesign loop also revealed tensions. Some students expected a clearer separation between theory and application and needed support to understand why open-ended design tasks, reflection and workplace-facing activities were central to the curriculum. Staff and workplace stakeholders also needed to negotiate the balance between technical depth and broader professional dispositions. Assessment design required refinement to ensure that EHoM were connected to demonstrable engineering judgement rather than treated as vague attributes. Such tensions are common in curriculum innovation, particularly where project-based, interdisciplinary or competence-oriented curricula require sustained alignment of pedagogy, assessment, staff practice and institutional conditions (Doulougeri et al., 2024; Graham, 2022; Kolmos et al., 2016).

Overall, applying the ST+EHoM model supported a shift from curriculum design as content organisation to curriculum design as socio-technical alignment. Systems thinking helped define the curriculum as an interconnected system shaped by academic learning, workplace practice, assessment, stakeholder input and feedback. EHoM helped translate programme aims into a language of engineering dispositions that informed learning outcomes, project design, assessment and reflection. The case therefore illustrates the model's value as a process for ongoing curriculum design rather than as a static framework. The next section considers what applying the model revealed, including its affordances, tensions and limits as evidence of curriculum development practice.

### **Affordances and tensions from the model application**

This section examines what applying the ST+EHoM model revealed in the curriculum development case. The focus is not on evaluating curriculum effectiveness or student outcomes, but on identifying what the model enabled, what tensions it surfaced, and what the case can and cannot support as evidence.

### ***Affordances of the model-in-use***

The first affordance was that the model shifted curriculum design from content organisation to socio-technical alignment. Rather than beginning only with module topics, technical sequencing or assessment requirements, the curriculum team was prompted to ask what kind of engineer the programme was trying to develop and what connected learning system would support that development. This was particularly important in a degree apprenticeship context, where students moved between academic study and workplace practice, and where coherence depended on the relationship between technical learning, professional development, employer expectations and assessment evidence (Billett, 2009; Laczik et al., 2024; Lester & Bravenboer, 2020).

The second affordance was that the model made stakeholder relationships more visible. Applying a systems-thinking lens highlighted that the curriculum was shaped not only by academic staff and programme documentation, but also by workplace engineers/mentors, employers, students, accreditation expectations and institutional quality processes. These actors influenced what counted as legitimate learning, credible assessment and appropriate evidence of professional development. The model therefore helped frame stakeholder engagement as part of the curriculum system's feedback and adaptation processes, rather than as occasional consultation.

The third affordance was that EHoM provided a shared language for engineering formation. Systems thinking, problem finding, creative problem solving, visualising, improving and adapting helped connect programme aims, project work, workplace reflection and assessment. This was useful because professional capability can otherwise be described in generic terms such as employability or transferable skills. EHoM enabled more specific design questions: where do students practise problem framing? How do they visualise system behaviour? How do they respond to feedback? How do they evidence improvement and adaptation? This supported a clearer connection between technical learning and engineering judgement (Lucas et al., 2014; Passow & Passow, 2017).

The fourth affordance was assessment alignment. The model encouraged the curriculum team to consider how technical performance and engineering judgement could be assessed together. Project outputs, reflective reports, team presentations, individual vivas and workplace-facing evidence each made different aspects of learning visible. Technical tasks assessed disciplinary understanding, while reflective and oral components probed how students framed problems, justified decisions, responded to feedback and adapted their work. In this way, EHoM became part of assessment design rather than remaining implicit or aspirational (Biggs & Tang, 2011; Boud & Molloy, 2013; Sadler, 1989).

Finally, the model legitimised adaptive redesign. During early implementation, students' difficulty connecting theoretical circuit analysis with practical system design led to additional formative activities, including peer walkthroughs and design sprints. These activities gave students structured opportunities to explain assumptions, visualise circuit behaviour, discuss alternatives and connect theory with implementation. This illustrates the model's adaptive function: feedback from delivery was used to redesign the learning environment.

### ***Tensions and limits***

The model also surfaced important tensions. The first concerned innovation and regulation. The curriculum sought to integrate systems thinking, project-based learning, workplace reflection and disposition-oriented assessment, while also satisfying quality assurance, apprenticeship, employer and accreditation requirements (Engineering Council, 2020; Gibbs et al., 2024). These requirements gave legitimacy, but also shaped what could be documented, assessed and evidenced.

The second tension concerned assessment. EHoM helped name forms of engineering judgement, but such dispositions are harder to assess reliably than discrete technical knowledge. Reflective reports, project work, vivas and workplace evidence created opportunities to assess judgement, iteration and adaptation, but they required clear criteria and staff calibration. Without this, EHoM risk becoming vague attributes rather than demonstrable features of student work.

The third tension concerned expectations and capacity. Some students expected a clearer separation between theory, application and professional development, meaning that open-ended design tasks and reflection required explicit scaffolding (Lowe et al. 2024). Staff also needed shared understanding, time for coordination and confidence with open-ended assessment. This confirms that the model depends on implementation conditions, not only conceptual coherence (Graham, 2012, 2022; Kolmos et al., 2016).

The case therefore suggests that the ST+EHoM model had practical value as a curriculum design process, but not that it has yet been empirically validated. The evidence is practice-informed and contextually bounded, drawn from one degree apprenticeship curriculum in a new provider with close employer involvement. The model should therefore be read as a transferable design logic rather than a replicable template. The next section considers the wider implications of this design logic for EEE and engineering curriculum development.

## Discussion

The ST+EHoM model offers a way of addressing a persistent curriculum design problem in engineering education: how to preserve technical depth while also preparing students to work with socio-technical complexity, exercise judgement, and adapt to changing constraints. Its value is not that it provides a new universal curriculum template, but that it gives curriculum teams a design logic for connecting technical learning, engineering dispositions, assessment, workplace relevance and curriculum adaptation.

The model's main contribution is to bring together two forms of curriculum work that are often separated. Systems thinking frames the curriculum itself as an interconnected system shaped by students, staff, modules, assessment, workplace learning, accreditation, employer expectations and institutional processes. This shifts attention from curriculum components to curriculum relationships, boundaries, feedback loops and points of misalignment (Meadows, 2008; Rahdar et al., 2023; Spain, 2019). EHoM then provide a language for the forms of judgement students are expected to develop: systems thinking, problem finding, creative problem solving, visualising, improving and adapting (Lucas et al., 2014). The model therefore connects curriculum-system design with student formation.

This contribution is complementary to, rather than a replacement for, existing approaches. Constructive alignment remains useful for linking learning outcomes, teaching activities and assessment (Biggs & Tang, 2011). CDIO provides a broader architecture for engineering education by linking disciplinary knowledge with personal, interpersonal and system-building skills (Crawley et al., 2014). Project-based and challenge-based learning create opportunities for authentic, open-ended learning (Doulougeri et al., 2024; Kolmos et al., 2016; Mitchell et al., 2021). However, these approaches do not always make the curriculum itself visible as a socio-technical system, nor do they necessarily specify how engineering dispositions are developed across the learning journey. ST+EHoM addresses this gap by asking how technical learning, assessment, feedback and professional formation interact across the curriculum.

The model's most distinctive conceptual move is the dual positioning of systems thinking. Systems thinking is both one EHoM and a broader design logic for the curriculum. It is also treated as a meta-

habit because it strengthens the other habits. Problem finding, for example, becomes more powerful when students consider boundaries, assumptions and stakeholder perspectives. Creative problem solving becomes more responsible when students consider sustainability, safety, usability and unintended consequences. Improving and adapting become more meaningful when students respond to feedback at the level of the wider system rather than optimising isolated components. This is particularly relevant to EEE, where students must move between components, circuits, devices, networks, infrastructures, organisations and societies.

The case also shows that the model is demanding to operationalise. First, it requires conceptual clarity. If EHoM are understood as generic soft skills, the model risks becoming another attribute-mapping exercise. Its value depends on presenting habits of mind as ways of thinking and acting through engineering knowledge. Second, the model places significant demands on assessment. Engineering dispositions are harder to assess than discrete technical knowledge. Problem framing, adaptation, improvement and systems judgement need to be evidenced through design rationales, testing records, reflective accounts, vivas, portfolios and workplace artefacts. Without clear criteria and staff calibration, assessment risks becoming vague or inconsistent (Boud & Molloy, 2013; Sadler, 1989).

Third, the model requires staff capacity and institutional support. It asks staff to work across module boundaries, design open-ended tasks, integrate workplace learning, interpret EHoM consistently and use feedback for redesign. These are significant demands, especially in technically dense EEE curricula. Curriculum reform literature suggests that sustainable change depends not only on sound design principles, but also on staff ownership, workload recognition, leadership and local implementation conditions (Graham, 2012, 2022; Kolmos et al., 2016).

The model is therefore transferable as a design logic, not as a fixed template. The case benefited from a new provider context, a degree apprenticeship structure, small student numbers, close employer involvement and opportunities for curriculum rebuilding. Established EEE departments may face larger cohorts, legacy module structures, distributed teaching teams and less direct workplace access. Transfer would require local system mapping, EHoM progression mapping, assessment redesign and staff development.

The model also remains underdeveloped in important respects. The claim that systems thinking is both a habit and a meta-habit is plausible, but needs further theoretical testing. The relationship between ST+EHoM and accreditation outcomes, CDIO, sustainability competencies and employability frameworks also needs clearer articulation to avoid adding to framework overload. Finally, the model's relationship to engineering identity formation requires further development, since it implies that students are not only acquiring skills, but developing ways of being and acting as engineers (Claussen et al., 2023; Godwin, 2016; Morelock, 2017).

Overall, ST+EHoM is best understood as a framework for adaptive curriculum alignment. Its strength lies in making curriculum relationships visible and connecting technical learning with engineering dispositions. Its limits are equally clear: it requires careful assessment design, staff development, student scaffolding and empirical testing before stronger claims can be made about its impact on learning or professional formation.

## **Future work**

This paper has developed the ST+EHoM model conceptually and illustrated its use through one practice-informed curriculum design case. Future work should now focus on theoretical refinement, practical implementation and empirical evaluation.

Theoretically, further work is needed to clarify the status of systems thinking within the model. This paper has argued that systems thinking can operate both as one Engineering Habit of Mind and as an integrative meta-habit connecting problem finding, creative problem solving, visualising, improving and adapting. This is plausible because systems thinking foregrounds interdependence, boundaries, feedback and adaptation (Meadows, 2008; Monat et al., 2022; Stroh, 2015), but the claim requires further conceptual testing. Future work should also clarify how ST+EHoM relates to existing frameworks, including accreditation outcomes, CDIO, employability frameworks and sustainability competencies (Biggs & Tang, 2011; Crawley et al., 2014; Engineering Council, 2020; Passow & Passow, 2017). This is important if the model is to reduce curriculum fragmentation rather than add another layer of complexity.

Further work is also needed on disciplinary specificity. Although this paper focuses on EEE-related curriculum design, different engineering disciplines involve different artefacts, practices and forms of judgement. Within EEE, future work could examine whether EHoM need adaptation to better reflect practices such as modelling, abstraction, debugging, simulation, signal representation, system integration, reliability, safety and security.

Practically, the model needs operational tools. These could include curriculum mapping templates, EHoM progression maps, assessment rubrics, reflective prompts, stakeholder mapping tools, mentor guidance and worked examples from different EEE contexts. Staff development will also be essential, since the model depends on shared understanding of how systems thinking and EHoM can be embedded in technical teaching, project work, assessment and feedback (Graham, 2012, 2022; Kolmos et al., 2016).

Finally, the model requires empirical evaluation. This paper examines the model-in-use, but does not demonstrate effects on student learning, professional identity, workplace performance or graduate outcomes. Future studies should gather evidence from students, staff, workplace engineers/mentors, employers, assessment artefacts and alumni. Longitudinal and mixed-methods research would be particularly valuable for examining how engineering dispositions develop over time and whether ST+EHoM-informed curricula support students in becoming engineers capable of reasoning, acting and adapting within complex socio-technical systems.

## Conclusion

This paper has argued that engineering curricula should be designed as socio-technical systems, not simply as sequences of technical content. The ST+EHoM model developed here combines systems thinking with Engineering Habits of Mind to support this shift. Systems thinking provides the design logic for understanding curriculum as an interconnected and adaptive system. Engineering Habits of Mind provide the language for articulating the forms of judgement students need to develop as emerging engineers.

The model's distinctive contribution is to position systems thinking both as a curriculum design logic and as an integrative habit that connects problem finding, creative problem solving, visualising, improving and adapting. This is particularly relevant to EEE-related curricula, where students must move between components, systems, users, organisations and wider societal consequences.

The practice-informed case shows that the model can support curriculum coherence, academic-workplace integration, assessment alignment and adaptive redesign. It also shows that implementation is demanding. The model requires clear assessment criteria, staff development, student scaffolding, stakeholder engagement and sustained feedback loops.

The ST+EHoM model is therefore not a universal template or a validated intervention. It is a transferable design logic for helping curriculum teams connect technical depth with professional formation. Further empirical work is needed to examine its impact on student learning, engineering identity and workplace performance across diverse engineering education contexts.

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## Declaration of interest

The authors declare there is no conflict of interest associated with this work.

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