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Exploring Practical, Disciplinary, and Engineering Reasoning in a High School Technology Classroom

Mathew Thomas

The Open Polytechnic of New Zealand, 3 Cleary Street, Waterloo, Lower Hutt 5011, Wellington, New Zealand,  0009-0005-4483-1441
Corresponding author: Tiju Mathew Thomas (mathew.thomas@openpolytechnic.ac.nz)

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Abstract

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This paper presents how students in a secondary school technology classroom navigated different forms of reasoning during the early stages of a design project to build gravity-powered street luges. The data collection methods included classroom observations, examining student artefacts, teacher interviews, and focus group discussions with students, the analysis identified three modes of reasoning, practical (trial-and-error), disciplinary (use of science and mathematics), and engineering (conceptual design integration). Findings show that students predominantly relied on practical reasoning early on in the project, with disciplinary concepts often referenced at a surface level. Engineering reasoning emerged later especially when triggered by testing failures or design constraints. This paper contributes to understanding how conceptual learning can be fostered through design-based activity and offers implications for strengthening interdisciplinary thinking in technology education.

Keywords

Technology education
Engineering reasoning
Science integration
Secondary education
Design-based learning

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Introduction

Introducing engineering design within secondary education has been widely suggested as a way to promote integrated interdisciplinary learning to cultivate critical 21st-century skills such as problem-solving, creativity, and systems thinking (Honey, Pearson, & Schweingruber, 2014; Williams, Nguyen, & Mangan, 2016; English & King, 2019; Kelley, Knowles, & Han, 2020). Across Australasia, school curriculum frameworks increasingly promote authentic task and design-based learning experiences that introduce young learners to STEM education, in particular to engineering concepts (Fleer, 2020; MacDonald et al., 2020). Understanding how school students use knowledge during early education is critical to informing future curricular design to promote interdisciplinary learning. Research suggests that school-level engineering design projects often elicit *practical reasoning*, a form of reasoning embedded in personal experience and empirical judgment rather than formal theory (Roth, 2001; English et al., 2013; Cunningham & Kelly, 2017; Crismond & Adams, 2012). While this form of reasoning plays a formal role in engineering, its dominance in design tasks can potentially compromise opportunities for deeper disciplinary learning, particularly if not intentionally supported by explicit pedagogical interventions.

This study investigates how Year 11 students from a New Zealand school reasoned through a year-long street luge design and construction project, with a particular focus on how they engaged with science and mathematics during the design stages of the project. In doing so, this paper intends to respond for calls within the Australasian engineering education community for meaningful practices in early engineering learning in schools (Huntington et al., 2020; Hadgraft & Kolmos, 2020; English, Hudson, & Dawes, 2012; Falloon, Powling, Fraser, & Hatisaru, 2022). This paper focus on three key findings derived from student data: (1) practical reasoning dominates early concept work; (2) limited application of scientific and mathematical knowledge; and (3) conceptual engineering reasoning emerged later, through contextual triggers. This paper will consider how pedagogical design might better support students in moving between intuitive knowledge and conceptual knowledge domains, assisting to align project-based learning with the goals of STEM education.

Literature Review

Engineering Design in School Contexts

Engineering education is gaining traction at school level across Australasia and beyond. Within the New Zealand Curriculum, for instance, engineering-related learning often falls under the ‘Technology’ subject in schools, where students are expected to engage in authentic *technological practice*, which includes planning, designing, making, testing, and refining design solutions (Ministry of Education, 2007; NZ Curriculum Online, 2018). Similar curricula are observed in Australia referred to as ‘Design and Technology’ which incorporates technological and engineering principles within design and digital technologies (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2022; Australian Curriculum, 2024).

However, introducing engineering design in school settings through Technology education comes with pedagogical and epistemological challenges. Research has shown that in Technology, educators often approach design problems through trial-and-error strategies or functional preferences rather than through systematic

application of science or mathematics (Williams, 2000; Wells, 2013; Reeve, 2015). While hands-on projects in Technology may engage and motivate learners and foster creativity, the conceptual and interdisciplinary depth of learning can vary widely, especially if connections to disciplinary content are not explicitly scaffolded during design tasks (Crismond & Adams, 2012; MacDonald et al., 2020; English et al., 2013).

Student Reasoning in Engineering Contexts

Literature indicates that school students' reasoning during design projects often takes the form of intuitional or *practical reasoning*, a problem-solving mode grounded in experience and localised logic (Cunningham & Kelly, 2017). Practical reasoning may involve observing physical phenomenon and behaviour, drawing on prior personal experiences, or replicating what has already worked previously. While this type of reasoning is prominent in engineering and even valued by seasoned professionals (Johri & Olds, 2011), it often lacks the conceptual underpinning that formal scientific and mathematical reasoning provides to practical actions. Early secondary school learners may even struggle to bridge experiential and practical learning with abstract disciplinary concepts (Honey et al., 2014; Pearson, & Schweingruber, 2014). Without strategizing intentional scaffolding, students may not see the relevance of science, mathematical, and engineering models to their design tasks, instead relying on what "feels right" or "looks good" (English et al., 2013). This implies that the cognitive potential of engineering design to integrate science and mathematics may not be realised and achieved.

Integrating Disciplinary Knowledge in Design

The integration of science, mathematics and engineering into design-based learning requires both curricular alignment and a well-planned and designed pedagogical strategy sustaining meaningful integration. Several research studies suggest that scaffolding students with targeted interdisciplinary inputs, either before or during the design process, can support more informed and theoretically grounded decision-making (Crismond & Adams, 2012; Wendell & Rogers, 2013). For example, research by Bethke Wendell and Rogers (2013) found that students who were explicitly taught concepts from science were more likely to apply them concepts in their prototype testing and further iterations.

However, the timing and context of such targeted interventions must be well thought and supported. Some research also suggests that students appreciate the intake of disciplinary ideas when they face design challenges that cannot be resolved through intuition alone (Wendell et al., 2017), or in other words, when students perceive disciplinary knowledge to be necessary to move forward in the design task. Under these circumstances, students may seek to understand scientific explanations or begin to recognise the value of mathematical analysis and engineering concepts. This highlights the importance of *contextual triggers*, stages within the design process that prompt students to shift from practical or tacit reliance and more towards conceptual reasoning.

Engineering as an Epistemic Practice

There is a need to understand how learners use, construct, justify, and apply knowledge within an engineering

context to appreciate engineering as a discipline (Duschl, Schweingruber, & Shouse, 2007). In engineering education, this would include how students define problems, generate optimal solutions, evaluate trade-offs, design, construct and communicate ideas clearly. Studies have shown that students' ability to construct knowledge and to defend knowledge claims develops unevenly across different stages of design and often depends on the nature of the design tasks and the support provided to navigate through the stages of the task (Cunningham & Carlsen, 2014; Cunningham & Kelly, 2017). This study contributes to the existing literature on epistemic cognition by understanding how students think, reason and learn during design contexts. This paper focuses particularly on how students use science and maths concepts while designing.

Theoretical Framework

This study is underpinned by a sociocultural view of learning that emphasises *situated cognition*, the idea that knowledge within is shaped by the social and material contexts of activity (Greeno, 2006; Vygotsky, 1978). Specifically, this paper draws on frameworks of *epistemic cognition* to examine and understand how students make sense of knowledge during their design processes (Sandoval, 2014). A distinction is made between three forms of reasoning that students exhibited during the project;

- *Practical reasoning*, rooted in intuition and prior experience and based on observable effects or aesthetic judgment (Cunningham & Kelly, 2017; English, Hudson, & Dawes, 2013);
- *Disciplinary reasoning*, reflecting students' engagement with formal disciplinary domains, particularly science and mathematics (Duschl, Schweingruber, & Shouse, 2007);
- *Engineering reasoning*, where learners not only design but also justify decisions based on evidence, conceptual understanding, and iterative refinement (Crismond & Adams, 2012; Cunningham & Kelly, 2017). These cognitive shifts in reasoning are not mostly linear; but rather activated by contextual triggers, such as investigations, design failure and reviews, and peer critique, which challenges students' assumptions and invite deeper reflection (Crismond & Adams, 2012; Bethke Wendell, Wright, & Paugh, 2017; Wells, 2013).

This categorisation of reasoning is underpinned by sociocultural perspectives on learning, particularly the view that knowledge is constructed through activity and shaped by the tools, language, and social interactions available within the learning environment (Greeno, 2006; Vygotsky, 1978). This analytical lens allows to explore how different reasoning modes emerged across initial phases of the design task and how these shifts were shaped by the context and student experiences. Understanding these connections are essential to designing more effective school-level engineering education that promotes interdisciplinary engagement.

Methodology

This study was conducted in a single-sex secondary school in New Zealand where a Year-11 technology class undertook a year-long project to design and build gravity-powered street luges. The participants in this study were nineteen male students (aged 15–16) and one male teacher with more than twenty years of technology teaching experience. Ethical approval for the study was secured through the University of xx's human resource ethics committee. Informed Consent forms were distributed and signed by all students, their parents/guardians, and the

teacher, and all names in the data set were replaced with pseudonyms for the purpose of maintaining anonymity and reporting. A qualitative case-study design (Yin, 2014) was adopted for this study because it allows detailed examination the case, which included one class, one teacher and students in this class working on a project, over a school academic year (Term 1 to Term 4). The guiding research question was how do different forms of reasoning emerge and interact as students engage with science, mathematics, and technology during an engineering design project in a secondary classroom?

The data collection took place over the four academic terms, four ten-week school terms that structured the project into four main phases concept design and material testing (Term 1), luge construction (Terms 2–3), and testing/evaluation (Term 4). Data collection instruments included classroom observations, informal discussions, interviews with the teacher, focus group interview with the students, photographs and students' final year portfolios. These sources were thoroughly studied to capture how practical, disciplinary, and engineering reasoning developed. Student talk and discussions were recorded to investigate the use of scientific or mathematical language during design decisions. Student portfolios (experimental conclusions, annotated sketches, testing logs) were collected at the end of each term, yielding design stages concept drawings which was useful for this study. Focus-group interviews (3–4 students each, \approx 35 min) were conducted in Term 4 to understand students' account of how design ideas changed across different design phases and what knowledge was drawn upon at various stages of the project. Interview with the teacher probed intentions for integrating disciplinary knowledge and teacher perceptions of students' reasoning.

All textual data were coded and systematically analysed. Following Braun and Clarke's (2006) thematic analysis, open coding was applied to classroom observation and informal discussion transcripts, classroom observation field notes, portfolio excerpts, and interviews, which assisted in generating an initial set of descriptive codes related to kinds of reasoning, disciplinary references, triggers highlighting idea change, and teacher assistance. These codes were then clustered into higher-order categories, practical, disciplinary, and engineering. Data-source triangulation (Denzin, 2012) strengthened credibility of the findings, for example, a student's claim in a focus group interview was checked against their portfolios and classroom observation notes and informal discussion records.

Prolonged engagement with the design context, which included ten months in the classroom and workshop allowed for gather intimate knowledge of classroom instructions, students' practices and classroom/workshop dynamics, reducing the risk of misinterpretation. Nonetheless, the findings are context-specific, and they highlight how STEM reasoning unfolding in a technology classroom and may require adaptation for other settings. By comparing classroom observations, students' own work in portfolios and artefacts, teacher reflections, and teacher perspective, this study offers a rich triangulated account of how practical, disciplinary, and engineering reasoning emerged while students worked on designing an artifact through concept negotiations.

Findings

This study aims to examine why secondary students struggled to apply science and mathematics knowledge in a

design-based engineering task. Data were drawn from students' concept diagrams, classroom observations, informal classroom discussions, researcher's field notes, student focus group interviews (term 4) and 1 teacher interview (term 1). Nineteen student concept diagrams were analysed, with each student assigned a pseudonym (AC, AD, BJ, etc.). While all students successfully produced labelled concept diagrams of their luges, most ignored explicit science or engineering concepts in their drawings. The findings section is organised around three key themes arising from the data sets:

- (1) practical reasoning dominates early concept work,
- (2) limited application of scientific and mathematical knowledge,
- (3) conceptual engineering reasoning emerged later, through contextual triggers.

Practical Reasoning Dominates Early Concept Work

In the early stages of the project, student reasoning was largely dominated by practical and observational logic, which was evident in their portfolios. Across interviews with teacher and students, student concept diagrams, and classroom observations, it was evident that students approached this phase of the design task through an intuitive, experience-based understanding of form and function of the luge. This practical reasoning stemmed strongly from reliance on visual cues from researching existing products (both physically and online), critical comparisons of luges, and assumptions rooted in common sense rather than relying on formal knowledge structures to derive conclusions and to draw diagrams.

For example, during classroom observations in Term 1, students were frequently seen browsing the internet (Google Images) for exploring different luge designs, printing them, and identifying materials and components-based function it fulfils within the design. Students like SS explained their selection of an online luge design by saying, "I'm pretty sure that I can't do that [pointing on one of the designs] ... that one looks too hard, I can probably do that one." Similarly, JS noted, "those are quite popular ones... see that one there... that's a pretty good one," indicating aesthetic looks of the design and accessibility as primary factors. The teacher's facilitation style supported this approach early on during the design stages, encouraging students to engage with real-constructed designs as a starting point (both in workshop and online), treating products as "textbooks" to be read visually and structurally, to understand its functionality.

In their initial attempt in drawing concept diagrams, most students drew components without accompanying functional annotations or the diagrams lacked details. Researcher notes for JS, for instance, revealed that his first concept diagram lacked labels altogether. Where labels did exist, they often labelled as parts without rationale (like "metal frame" or "plywood bodypan"), suggesting that design choices were initially based more on understanding existing products and replication than understanding. The teacher's comment in the Term 1 interview mentioned "as long as you got something on your piece of paper where you can bring to me and say 'sir, what do you think about this?'" further highlighting the significance of the tacit, trial-based approach dominant at this phase of the project.

Focus group interview reflections in Term 4 confirmed that this early phase was practically driven for all students,

in the sense that existing products gave them the headway to design their own luges. Students like JC and TG clearly highlighted they "just looked at it" or "read it and figured out it works this way." LG referred to his reliance on online information sourcing, stating, "we don't have a lot of IT at the school and [I was] skimming down a website and saying I want that particular information." Here, practical reasoning involved both understanding physical properties and information literacy, identifying manageable and reasonable design options based on what could be quickly accessed, implemented and constructed.

The concept diagrams from students such as BC, DC, and LG further assisted in validating this theme. In BC's first concept drawing, the luge lacked ergonomic or performance-based consideration, and only later, in the third drawing did the student adapted the body pan and acknowledged its 'curved shape' for shoulder steering (see Figure 1). LG's diagram, while detailed and showed components and materials used, showed no consideration for centre-of-mass placement or aerodynamics in the early versions of the diagrams (see Figure 2). This pattern was common amongst other students as well, initial designs lacked conceptual insights but were visually rich, reflecting practical reasoning based on past experience, product research, and ease of construction.

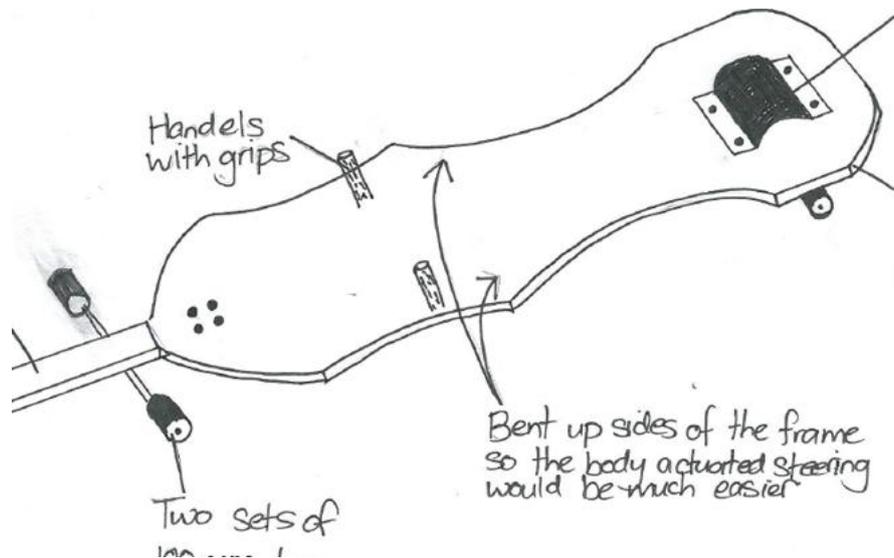


Figure 1. BC's Initial Concept Drawing

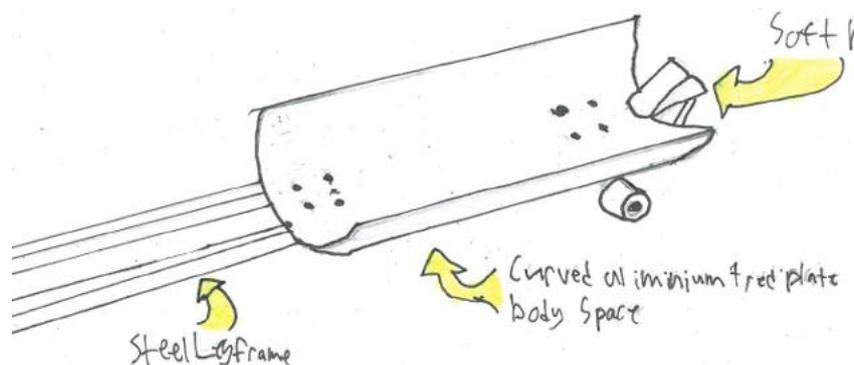


Figure 2. LG's Initial Concept Drawing

Limited Application of Scientific and Mathematical Knowledge

Across all sources of data collected and analysed, there was clear evidence of limited integration of science and mathematics during this phase of the project. While students often referred to concepts like "speed" or "momentum" in their focus group interviews, their application of these concepts were rarely systematic during the design and testing phases. Mathematics was used in minimal and in procedural ways, mainly to support measuring, drawing and scaling activities.

As observed in Term 1 classroom observations, students were introduced to the concept of product reading and luge analysis as a skill to understand existing products but made little mention of any physics concepts or mathematics beyond the use of surface-level terms within the context of the design. The teacher explicitly prompted students to think about 'weight distribution' and 'aerodynamics', yet written responses in the form of conclusions remained vague. For instance, during discussions initiated by the teacher in class on why body pans are curved up shape, BC asked, "what sort of steering do they have?" suggesting a focus on understanding procedural knowledge of the components rather than conceptual grasp. It was also noted that while the teacher encouraged students to understand steering sensitivity adjustments through tightening bolts, student uptake remained limited at this stage. A possible explanation could be the lack of context related experience of luge construction and steering adjustments at this early stage of the project.

The teacher interview in Term 1 further clarified this limitation, observing that "sometimes they don't know that they are doing it... but they have to because how else could they do things." This highlights a potential disconnect between students' actions and their conscious use of disciplinary knowledge from science and mathematics, suggesting that while students may engage with relevant ideas like steering or weight distribution in a practical manner within the context of the design, they often lack the conceptual framing to describe or apply them meaningfully. This view was echoed in the focus group interviews conducted in Term 4: when asked specifically about science or maths used during the momentum testing phase, JC without any hesitation said, "not really, you just watched." TG added, "it was more like testing like where to get the speed bump to like weight," showing an informal, empirical approach rather than analytical reasoning.

Where mathematics did appear, it was largely procedural. Most students mentioned taking measurements, applying symmetry, and scaling in their concept drawings. MY explained that during the phase of sketching and drawing concept diagrams, "positioning of the wheels had to be right and in parallel lines," while JP noted, "scales and stuff... you need to get it all right... also looking for symmetry and balance." LG added, "just basic maths and drawings," which confirms the emphasis on applying practical geometry over more formal analytical mathematics (see Figure 3 from student KM's portfolio where practical geometry was used to draw symmetrical diagrams).

Despite these instances, deeper concepts like force, acceleration, or friction were rarely explored in meaningful ways in the class. Even during the wheel testing or momentum testing phase, which could have provided a direct context for scientific application, students like MC dismissed the value of cross disciplinary learning during this

phase: “the weight of the pilot was not helpful because I think I can’t make myself fat for one race to go faster.” Such comments suggest a disconnect between experimentation and transferable insight. A Student described the wheel testing phase as confirmatory rather than investigative. JC admitted he had already chosen wheels from his brother’s board and that the testing was “nothing like [that]... just to see which wheels was best.”

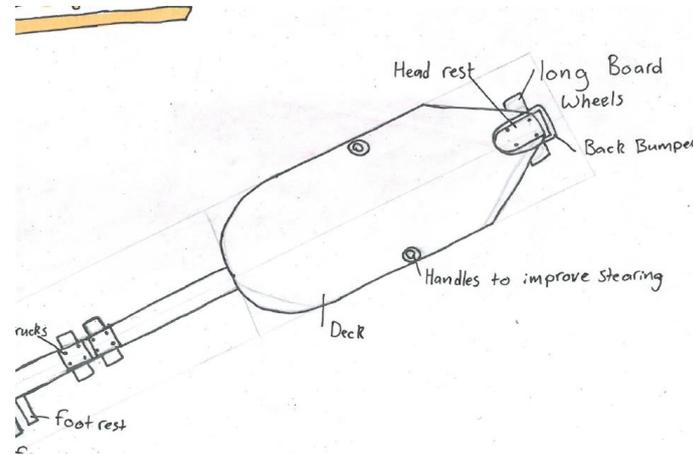


Figure 3. Student KM’s Concept Drawing Using Symmetrical Geometrical Lines

In the context of luge research and body pan design, students made casual references to ‘gravity’ and ‘centre of mass’ but struggled to connect these ideas to their design modifications. For instance, MY observed:

“That also was a downside for us too because there were a couple of people from the class whose body pans were too low and when they turned, they just scraped it on the ground.”

And LG added:

“A lot of the lower luges, they would not get the speed wobbles at all but again they would not turn... you can look at it and say this is the centre of mass, but when looking at it from the practical side then no, that doesn’t work.”

These remarks suggest that while students recognised the relevant concepts from science, their understanding of such concepts was experiential and not planned in advance. This practical reasoning stayed anchored in observation and within the context of the product, rather than using physics principles to anticipate performance. This theme elaborates that while students were immersed in design rich activities, students were particularly focused on understanding practical and procedural aspects of the product. The data suggest that although science and mathematics were embedded within the context of the design, their cross-disciplinary application was underdeveloped during most of Term 1 activities.

Conceptual Engineering Reasoning Emerged Later, Through Contextual Triggers

The most significant shift in student thinking was observed when they began to move from practical ideas and concept designs to more engineering-focused reasoning as they began constructing their luges. This shift was not consistent across all students but was often triggered by specific experiences that changed how they understood the design problem. These included moments such as a luge failing during testing the constructed luges on the

racetracks, discussions with peers or teachers, or input from visiting experts on the race day. These experiences encouraged students to critically think more deeply about concepts like speed, weight, and aerodynamics, and to apply them more intentionally in their design decisions.

The teacher interview highlights a purposeful but flexible strategy: “We start to research these different areas... then we start to diverse into the maths and science sort of things.” He mentioned how guest speakers, like a physics teacher and a local engineer in Term 1, enriched the classroom dialogues around material properties and strength, rolling resistance, and structural profiles of luges. Such input from external experts played a crucial role, helping students shift their understanding from visual copying to product understanding and mechanistic reasoning.

The data from focus group interviews support this progression. Students like ST and JP began articulating deeper scientific principles by Term 4. For example, ST noted, “we definitely know the science... weight of the pilot is a major part of the speed,” while JP added, “you get more momentum if you are heavier and faster... momentum is mass times velocity.” Such data shows an understanding developed by students, possibly consolidated through repeated exposure to science concepts throughout the academic year and hands-on application while working on their luges.

Student design decisions also matured and began to reflect this reasoning. For instance, students LG and MY discussed lowering body pans to reduce ‘centre of mass’ and to reduce speed wobbles, a design decision which was validated through both practical testing on the luge testing day and theoretical framing. As MY stated, “if it is high and you get speed wobbles then you can fix it by tightening the trucks,” reflecting field based practical reasoning. Similarly, JP showed an applied understanding of aerodynamics: mentioned during the focus group that

“making the body pans and the frames streamlined so you can reduce the drag like putting a big flat plate at the front where you got the arrow so the wind can pass through it and make it faster” (JP, Focus Group)

Student JP’s final concept diagram reflected this understanding (see Figure 4). In their final concept diagrams, it was observed that students began to highlight logic related to performance in their sketches. For example, BC’s third and final drawing included annotations for the body pan as “bent-up sides of the frame so the body actuated steering would be easier,” a design feature absent in earlier versions. DR’s diagram also emphasized “drop for speed,” referring to the drop of the body pan lower to the ground (see Figure 5), linking form to function explicitly. EH annotated in his concept drawing “smooth shape for aerodynamics” and “heavier aluminium frame would gather more speed,” reflecting a systematic synthesis of luge research, wheel testing, and design refinement.

This transformation was achieved by implementing a classroom environment that encouraged trial and error and creativity. Observations from Term 1 showed how students were allowed to sketch multiple concept drawings after performing research on existing luges and revised drawings based on feedback received from the teacher. The teacher’s strategy to allow students “start simple and get more complicated as we go” helped them to scaffold the evolution of the product. By Term 4, many students were in a position to test and practically understand a

luge that worked, which not just looked good as a concept.

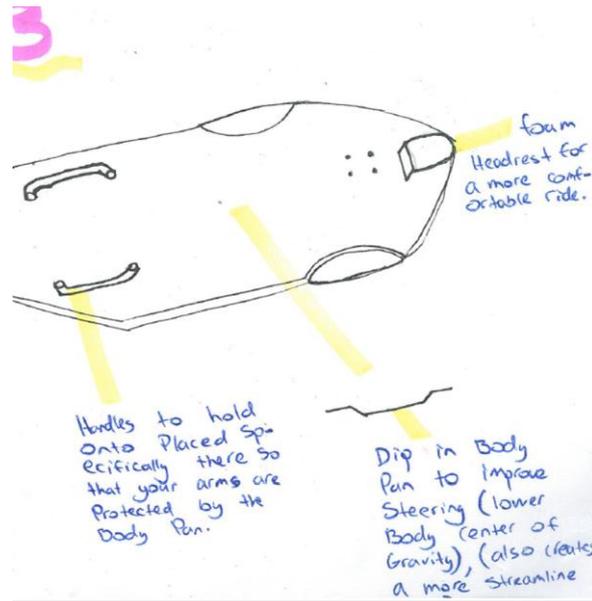


Figure 4. Student JP's Final Concept Drawing Showing Early Concepts of 'Centre of Gravity' and 'Streamline'

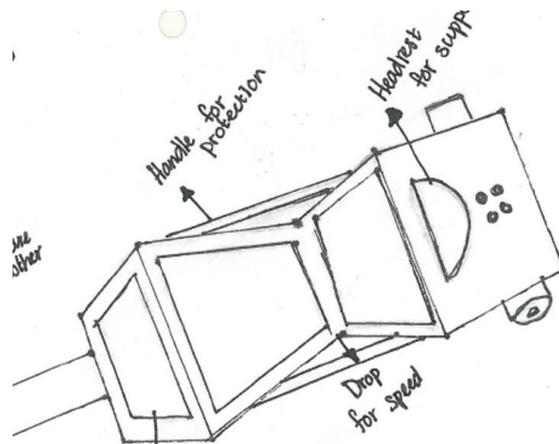


Figure 5. Student DR's Final Concept Drawing Showing 'Drop for Speed'

In the luge research and reflection phase during the focus group interview, JP and ST reflected how they responded to steering and stability issues on the day of testing by modifying the body pan and frame configuration. JP explained:

"Yeah definitely like making the body pans and the frames streamlined, so you can reduce the drag... like putting a big flat plate at the front where you got the arrow so the wind can pass through it and make it faster."

ST followed up with:

"We dropped our body pan down... just brought the centre of gravity down."

Such reflection and thinking demonstrates a link between observed performance issues of the product (like drag, riding instability) and practical applied adjustments based on the knowledge of science, namely aerodynamics and centre of gravity. Unlike earlier phases of the project where such concepts were mentioned abstractly, here the

students described modifying their physical design in response to practical constraints, demonstrating the emergence of engineering reasoning through contextual triggers. While not all students made this leap, there was strong evidence in the dataset that conceptual engineering reasoning emerged for many students through contextual involvement in authentic design tasks. The shift was not driven solely by the curricular content, but also through practical meaningful contexts that built upon existing knowledge and constructed new contextual knowledge, which exposed knowledge gaps which required practical reasoning to bridge them.

Discussion

This study dwelled deep to explore how students engaged with science, mathematics, technological and engineering knowledge during the early stages of a design project in a secondary school setting. Through classroom observations, exploring student concept drawings and retrospective interviews, this study has identified three dominant patterns of reasoning in this classroom, practical, disciplinary, and engineering, and investigated how these modes emerged and interacted across the course of the luge design project. In this section, we interpret the findings and discuss them in detail, and suggest implications for future research and practice.

The Default ‘Practical Reasoning’

The first key finding from this study is that practical reasoning was the dominant mode of engagement during the initial phases of the luge design project phases. Students relied heavily on prior experience, visual inspection of existing products, material properties and knowledge, and product engineering to make design decisions. Rather than drawing upon explicit scientific or mathematical knowledge during the design stages of the project, students relied on intuitive logic, empirical trial-and-error, or aesthetic criteria to proceed through the design stages. This was especially evident in their early conceptual sketches, in classroom exchanges of discussions, and in their reflections during the focus groups interviews. For example, students selected various components of the luge such as steering system, footrest or headrest based on perceived popularity of various designs available in the market, combined with the ease of construction, rather than performance efficiency.

This finding closely aligns with previous research aimed at understanding young learners' engagement in engineering design, which reported that students commonly relied on everyday or practical reasoning in design-based contexts (English, Hudson, & Dawes, 2013; Wendell & Rogers, 2013). Practical reasoning serves as a legitimate starting point in design activities and can scaffold deeper engagement if appropriately supported (Cunningham & Kelly, 2017). However, the persistence of this mode of reasoning in design tasks without transition to disciplinary thinking may explicitly limit conceptual learning, particularly when complex design decisions are required to be made.

While the luge project provided an engaging and authentic context aligned with the curricular aims of technology education, there is immense potential to provoke deeper reasoning, in the early stages of the project. The early stages of the project relied heavily on student-led exploration of the product. This approach while valuable, did not offered cross disciplinary cognitive challenge apart from practical reasoning. Introducing more structured

uncertainty and competing engineering constraints earlier in the design phase could prompt students to engage more analytically with the underlying principles of engineering. These refinements would only enhance the authenticity of the design task by supporting a more deliberate transition from intuitive decision-making to conceptual and engineering reasoning.

Limited Use of Explicit Scientific and Mathematical Knowledge

A second major finding from this study was that students made limited use of science and mathematics during the early stages of the design, which included wheel testing and conceptual drawings. While students could sometimes recall and connect key concepts such as speed, mass, or friction, they rarely used these ideas systematically during the initial stages of the design to inform choices. When students were prompted during the focus group interviews in Term 4, they often referred to these concepts at a surface level and often unsure about their relevance to the context. This finding was reflected in both the focus group transcripts and classroom observations, where students focused more on functional modelling than conceptual disciplinary reasoning.

Previous studies have reported that the integration of science and mathematics within engineering contexts are often inconsistent, and that students often struggled to transfer prior disciplinary knowledge within engineering design contexts (Honey, Pearson, & Schweingruber, 2014; MacDonald, Hunter, & Kempa, 2020). Even when teachers introduce ideas from other disciplines related to the design context, as occurred in this study, students may struggle to apply them meaningfully (Wendell, Wright, & Paugh, 2017). In this study a physics teacher was invited to do lessons on gravity, momentum and friction in week 1. Students did not find the information relevant and struggled to apply them within the context of the design.

Temporal separation of subject areas in school timetables could be a possible reason contributing to this uptake. As the teacher noted in his Term 1 interview, students “don’t know that they are doing it... but they have to,” implying that the integration of disciplines are often not explicit, unconscious and unstructured. This presents a structural challenge for schools, where disciplinary silos make real-time cross-subject application difficult, but a potential opportunity as discussed earlier.

Another limitation of this study is that it documented students' verbal and artefactual expressions of knowledge related to their concept drawings, it could not always determine what students knew but chose not to articulate. That is students may have had relevant science or mathematics knowledge but did not express it verbally or showed it in their produced drawing. This is a limitation with qualitative study, there remains the possibility that some disciplinary knowledge was present but unarticulated by the students.

Contextual Triggers Promote Engineering Reasoning

The final and most significant finding of this study was that challenges that are part of the design, such as physical failures and product testing, and peer critique (offered by experts like teacher and peer students), often provided an opportunity as a contextual trigger for students to shift from practical or disciplinary reasoning to what this

study identifies as *engineering reasoning*. This form of reasoning reflected an integrated, adaptive approach between engineering and technology, in which students used conceptual understanding to make informed design decisions under constraints. For example, students who encountered steering instability on the day of luge testing began to experiment with body pan height from the ground and frame adjustments in the field, linking ideas about centre of mass and aerodynamics to tangible changes in design, encouraging engineering thinking.

This finding agrees with other research based on design-based learning, where the significance of iteration, reflection, and failure in developing engineering thinking is well articulated (Crismond & Adams, 2012; Dym et al., 2005). These contextual triggers promote a shift in cognition by challenging the boundaries of students' intuitive reasoning. Such contextual triggers encourage students to explore new explanations or revise assumptions initiating engineering thinking, which is an important component of epistemic growth in engineering education (Cunningham & Carlsen, 2014; Sandoval, 2014).

It is worth noting that these transitions did not occur uniformly across all learners in this class. Some learners remained and preferred to stay in a practical reasoning mode throughout the project, particularly those students whose luge did not fail in the first attempt. This suggests that productive failure, a concept well supported in engineering education research (Kapur, 2014) may be a useful lens for future pedagogical design to incorporate engineering reasoning. Structuring tasks so rigorous testing of the final product is a part of the wider design activity may encourage students to reframe problems and seek conceptual engineering problem solving. Nonetheless, this study acknowledges that not all classroom environments facilitate, permits or tolerate failure equally, as in the first instance, developing a perfect functional product will be the focus. Implementation time and access to the right resources will most definitely be a major constrain in implementing trial-rich pedagogies.

Implications and Overarching Conclusions

The findings from this study suggests that secondary school students engaging in open-ended and authentic design tasks tend to begin with practical reasoning, draw on disciplinary knowledge only occasionally and unevenly, and only develop integrated engineering reasoning when prompted by contextual triggers within the context of the design. This has important implications for encouraging engineering design and thinking in schools. Practical reasoning is essential and should not be undermined but be recognised as a legitimate entry point in learning by design. Learning could be facilitated by teachers who can build on students' experiential logic by introducing targeted questions or sub-activities that prompts deeper reflection. Second, interdisciplinary connections need to be fostered and sustained within the context of the design and be perceived relevant by the learners. Disciplinary information should not be front-loaded and introduced early in the process as isolated content. Introducing conceptual checkpoints where students are expected to justify or model their design logic, may encourage more intentional integration. Third, providing opportunities for product testing, failure and fix iterations can help promote engineering reasoning within the context of the design, especially when paired with expert scaffolding, timely feedback and peer dialogue.

Even though this study was conducted in a single school, the data builds to a transferable framework for thinking

about reasoning modes in early engineering education in technology classrooms. While technology and engineering projects in secondary schools are often framed as interdisciplinary opportunities, the depth of integration depends significantly on the design task and how reasoning is scaffolded, implemented, and supported. By understanding how students think and reason, and by creating learning experiences through design that promotes conceptual transitions, educators can more effectively prepare learners for the epistemic demands of technology and engineering in the real world.

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