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# Design thinking and inquiry behaviours are co-constituted in a community of inquiry middle years' science classroom context: Empirical evidence for design thinking and pragmatist inquiry interconnections

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**Abstract**
Design thinking has been propositioned to be interconnected to Dewey's notion of pragmatist inquiry and aesthetic experience. To address the need for empirical studies on design thinking in the classroom and add to our understanding of its characteristics, this study explored middle years' students' discourse as they worked through a design challenge. Design thinking has been proposed to rely on inquiry as well as language in the form of specialised vocabulary and representations but how these intersect has not been studied. In this study, discourse analysis of inquiry and design behaviours during a design task and pre- post-testing of scientific language and representations is compared across two groups, one that engage in a design task embedded in an inquiry science unit, and one that also engage in a community of inquiry (CoI). The two groups are referred to as Non-CoI and CoI groups respectively. The hypothesis that CoI can enhance both the design process as well as accurate use of scientific language and representation in a design context was shown by contrasting CoI and non-CoI group test outcomes and small group design task discourse analysis. In this study, design and inquiry processes were synergistic, mutually reinforced each other, and were co-constituted through imbrication. The findings of this study have implications for science teaching using design thinking in a middle years' classroom.

**Keywords** Collaborative learning · Design thinking · Discourse analysis · Inquiry-based learning · Middle school

## Introduction

The proposition that design thinking is interconnected to John Dewey's notion of pragmatist inquiry and aesthetic experience has been thoroughly discussed in the literature (Dalsgaard, 2014; Rylander, 2012). Key to this discussion is that pragmatism is a

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paradigm of inquiry that offers a conceptual framework for fostering design discourse and practice. Dalsgaard argues that "the pragmatist conceptualisation of inquiry can offer insights concerning how designers' approach and explore design challenges" (p. 149). Moreover, that pragmatism is the ideal lens through which to explore and fully describe design thinking and inquiry. This study sought to explore design thinking and inquiry in the science classroom from the pragmatist position and add to our understanding of its characteristics through an analysis of middle years' students' discourse as they worked through a design challenge.

In our previous studies within the science classroom we have shown that the pedagogical practice known as the community of inquiry (CoI) has educational value (Nichols et al., 2017). The community of inquiry is a pedagogical activity that utilises a philosophical approach to foster classroom dialog. However, educational practitioners and theorists can neglect to keep in mind that CoI has a much wider use. The process of the CoI has a core intention to promote the skills and competencies to participate in the practices of discipline-based communities of inquiry and in that process take on the habits and behaviours of the disciplines. And further, "not only to aspire to competence within the disciplines, but to develop habits of self-correction for reconstructing those same norms [habits and behaviours] when faced with novel problems and solutions" (Burgh & Nichols, 2012, p. 1047). Indeed, we have shown previously through discourse analysis of inquiry behaviours, that CoI in the science classroom promotes students substantive questioning and other inquiry behaviours and supports a deeper conceptual understanding of science phenomena (Nichols et al., 2017). The proposition here is that there is educational value of CoI as a pedagogical tool for design practice in the science classroom. CoI, with its pragmatist roots, has implications for design practice and thinking within a science classroom and the role of educational philosophy in fostering students' ability for design thinking.

The development of the process of classroom CoI by Matthew Lipman was informed by Dewey's conception of reflective education, pragmatism and the implied pedagogical guidelines in his works (Burgh & Nichols, 2012; Lipman, 2008). Dewey was influenced by C.S. Peirce's conception of CoI, especially its accentuation of the pragmatic endeavours of fallibilism and self-correction (Dewey, 1916). Lipman adopted Peirce's ideas of CoI wherein "the practice of philosophy is the methodology of education" (Burgh & Nichols, 2012, p. 1047). However, it should be noted that Dewey did not espouse the practical use of philosophy in education.

However, Dewey points out in How We Think, learning 'is not learning things, but the meaning of things' (1933, p. 236). By this he meant that there is more to learning than the study of material objects, but that learning relies on a philosophical task of determining and representing the meanings these objects have for us, for our experience of the world relies on meaning to interpret it, which is always a learned response (Burgh & Nichols, 2012). Dewey held to the notion of pragmatism where "experimentation, reflection and action are intertwined as hypotheses and conceptualizations are informed by, directed at, and tried out in practice" (Dalsgaard, 2014, p. 149). Much like design, pragmatism asserts that "practice is the essential test bed in which conceptualizations prove their value" (Dalsgaard, 2014 p. 148).

This paper outlines the emerging nature of design thinking and practice from a positivist paradigm evolving into a more social constructivist and pragmatist paradigm. This leads to a discussion of the relationship of design thinking with Dewey's pragmatist inquiry followed by empirical data demonstrating a higher level of design and inquiry behaviours in a CoI context. Students exposed to CoI also show significantly higher accurate use of scientific language and representations. The paper concludes by discussion of the implications of CoI-focused teaching on inquiry behaviours and design thinking skills in science.

## The evolving nature of design thinking

Design thinking with its origin in the positivist paradigm started with the need to design innovations objectively and rationally. This desire to construct new things was then broadened to include the application and involvement of social interactions which gave rise to design methodology as a field of inquiry (Cross, 2001). Some scholars and especially design theorists treat design science as a discipline in itself (see for example Cross, 2007). Other scholars use a design approach within their own discipline such as in engineering and architecture (Dym et al., 2005; Lawson, 2005; Spee & Basaiawmoit, 2016) business studies (Brown, 2008; Bruce & Bessant, 2002; Camillus, 2008; Fraser, 2007) management sciences (Boland & Collopy, 2004; Cooper et al., 2009; Dunne & Martin, 2006; Johansson-Sköldberg et al., 2013), organizational studies (Dunbar & Starbuck, 2006; Jelinek et al., 2008; Romme, 2003), and social development (Bate, 2007; Brown, 2009).

Over the years there has been a shift in focus from an object-based design science to a more human-centred design thinking that involves dealing with complex situations requiring knowledge, skills and behaviours from multiple disciplines. Herbert Simon (1916–2001) as the founding father anchored design science in engineering to create new things objectively and rationally in a positivist way (Huppatz, 2015). Schön (1983), a pragmatist philosopher, offered a constructivist paradigm to design science (Waks, 2001). In his book *The Reflective Practitioner*, he argued that it is through the design thinking process that practitioners bring their abilities, skills and intuitive knowledge to deal with the messy and problematic situations termed by Rittel and Webber (1974) and Buchanan (1992) as 'wicked problems'. Schön (1983) characterized a "designer" as a practice-based individual who can create and reflect upon the creation, improve the skills and knowledge and re-create with an artistic touch of the practitioner. He argued that an objective approach to design thinking can undermine the creativity of the artist in the design process.

Taken further, Krippendorff (2005) forwarded the idea that a designed artefact communicates and is a medium of communicating meanings, however abstract, codified or theorized. Verganti (2006) applied this meaning-making to innovations, particularly technological innovations, framing objects that individuals can feel attached to in a meaningful way. This progress of design thinking from an objectivist approach to the involvement of human creativity and the meaning that the design communicates, indicates that design thinking is dynamic, contextual and an evolving phenomenon.

Given design thinking has had a shift of focus from objectively designing innovation to solving complex problems involving humans and their intuitive knowledge and expertise, there is a critical need to analyse design thinking from a social constructivist perspective. A recent review of design thinking in social sciences by Rylander (2012) proposes that "design thinking is a concept and a discourse in need of a theoretical framework, backed up by in-depth empirical studies, to be properly understood" (p. 217). Rylander explored design thinking as pragmatist inquiry, based on the American philosopher and educator John Dewey's theory of pragmatist inquiry. Rylander argued, the way Dewey describes pragmatist inquiry in relation to experimentation and aesthetic experience also applies to design thinking practice that operates "in the space between knowing and doing, alternating between problem-finding and problem-solving, using sketches and prototypes to arrive at a final solution" (p. 228). Dewey's notions of aesthetic experience can be applied to design thinking in that he suggests that arriving at a solution requires an interaction between meaning making and the design product, object or model. This paper is an attempt to expand on Rylander's theoretical argument and understanding of design thinking as similar to pragmatist inquiry through an empirical study.

## Design thinking and pragmatic inquiry

Dewey positioned pragmatism in education. He is well known historically for his educational and social reforms. His profoundly pragmatic approach focuses on reflective thinking and the reconstruction of intellectual habits through personal experience and its inextricable links to education. Dewey's educational theory draws on the tenets of pragmatism, asserting that knowledge is gained through thinking in the context of action or experience, and further to this, experience is 'intelligent thinking' (Dewey, 1916). He viewed inquiry learning holistically as a continuous interaction between meaning-making and objects aimed at an active restructuring of perspectives, thinking and conditions, much like design thinking practice. Dewey explains design practice intuitively as 'the operative force of both ideas and facts is practically recognised to the degree that they are connected with experiment' (1933: p. 110). This perspective draws together the objectivity and subjectivity of the design thinking process.

A major focus of Dewey's theory of inquiry was the intent to reconcile dualisms between thinking and doing, theory and practice (Rylander, 2012). Dewey proposed that higher functioning cognitive abilities such as reasoning and conceptualisation emerge from and are shaped by our abilities to interpret and perceive things, manipulate objects, move objects, models or prototypes in space and reflect on these actions. Such reasoning and conceptualization highlights the creativity of the reflective practitioner.

In the design process, ideation is a critical component. However ideas are informed by facts, useful only if they support each other and the ideas; and this directs the design activity; planning and further action to inquiry. An integral part of this ideation inquiry process is aesthetic experience that individuals bring to it and the meaning it communicates. This design thinking process is like pragmatist inquiry in that it involves the intellectual elements where experience has meaning and the practical elements of aesthetic practice through interacting with objects and events.

Dewey (1916) asserted the notion that humans are predisposed to take action when faced with problematic issues (Buchanan, 1992; Rittel & Webber, 1974) arising within their environment and it is through reflection on action that the habits formed in one's environment are re-evaluated and reshaped. Dewey saw inquiry as a continual process of reconstruction and intellectual growth and suggested the need for schools to become 'laboratories of knowledge making' (Dewey, 1916; Gregory & Granger, 2012). McKenna (2014) emphasized, students' knowledge development needs to include problem situations where they "learn from and about the problem, while continually reflecting on, and possibly reshaping, prior knowledge and experiences" (p. 232). Peirce (1887), the originator of pragmatism, referred to inquiry as the space between genuine doubt and a fixed belief. Peirce perceived genuine doubt to occur when an action, problem or 'real' experience brings about a feeling of disequilibrium resulting in one's need to revise an existing belief. It is this need that elicits inquiry based on the epistemic position of fallibilism (Chiasson, 2005).

Dewey's notion of inquiry and educative experience is exemplified and modelled in the classroom through the pedagogical approach known as a community of inquiry (CoI) developed by Matthew Lipman (Kennedy, 2012; Lipman, 2003). Kennedy (p. 28) argues that "the logic of CoI is Deweyan and Pragmatic for it is based on problematization in the interest of the improvement of a lived situation". CoI engages children in communal philosophical dialogue oriented to "clarifying, coordinating, instantiating and evaluating the ideas that emerge from each participant in the group" (Kennedy, p. 40).

Dewey's inquiry model and the CoI process parallels the design process with three key stages. The first stage is the initial problematizing of a situation in which individuals come to experience a sense of disequilibrium. The second stage is when the problematic situation is dissected and deconstructed. Finally the third stage is a reflective process whereby possible solutions are tested and evaluated through engagement in self-corrective reconstruction of habits. The restructuring of experience and thinking is expressed through objects of design as well as language as symbols or diagrams (or representations) and specialised vocabulary (in the case of science this is scientific language). The development of these habits has the potential to impact on skill development in science classrooms.

## Construction of language through inquiry and design thinking

Rylander (2012, p. 234) argues that in design thinking "an idea must be embodied, as a symbol [specialised language or representation], so that we can look at it, for it to be useful in the process of inquiry". Rylander suggests that we need to theorize design practice by exploring it empirically at the level of this aesthetic experience and inquiry. In direct contrast, Dewey's notion of aesthetic experience involves meaning making (through specialised language and representations) in interplay with the artistic product, drawing or prototype.

In the design process that includes investigating, defining, designing, evaluating and the negotiation, are active linguistic elements of a specialised language that are shaped, reshaped, reformed, extended, instigating new thought and ideas, and confirming conjecture (Bucciarelli, 2002). It is these linguistic elements, the specialised vocabulary and representations of the product being designed that bridge thought and object, intended function and structure. It is the experience that the designer brings to the making of the object, and the meaning that the object communicates which is the aesthetic dimension of the design process. Bringing the dualism between thought and object, thinking and doing, is the language, of science and engineering. This study proposes that the inquiry behaviours acquired through engaging in CoI (Nichols et al., 2017), will provide a way to more deeply engage in the linguistic elements of design and design practice, to turn the object of design around, critically appraise it and creatively ideate, troubleshoot and problem solve. The action through reflection is what develops the habitus of mind to construct and re-construct (Dewey, 1916) not only the object development but also students' knowledge and behaviours. The proposition here is that CoI can support middle years' students to better engage in the design process by developing design skills and 'a stance towards inquiry' or inquiry behaviours that Christensen et al. (2019, p. 651) have shown are not automatically acquired when they engage in practical encounters with design processes.

## Purpose of the study

The purpose of this paper is twofold: to provide empirical evidence to support the theoretical foundation of design thinking using Dewey's pragmatism (see Rylander, 2012; Dalsgaard, 2014); and to use the evidence to highlight the outcomes of students learning in a design thinking and CoI context. If we accept the theoretical links between Dewey's pragmatist inquiry and design thinking process thoroughly discussed by Rylander (2012) and Dalsgaard (2014), then by inference engaging in these processes together should foster design and inquiry behaviours as well as enhance the expressions of thinking as language and aesthetic objects or representations of ideas. The empirical study posed to explore the following questions. (1) What are students' patterns of design and inquiry verbal behaviours during a small group design task with and without CoI pedagogy in a science classroom? (2) How does engaging in CoI impact on students' use of scientific language and representations during a small group design task?

## Method

### Participant demographics and recruitment

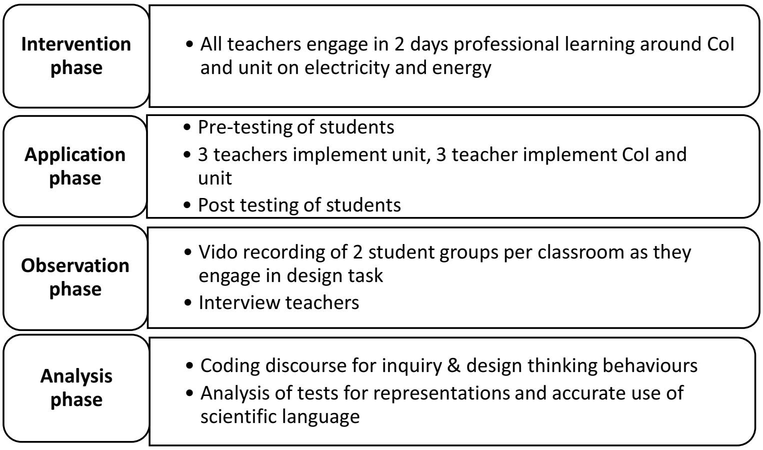
Participants included six Year 6 middle years' teachers and their 159 students recruited from four municipal and regional schools of Queensland, Australia, with similar sociodemographic profiles (school size range from 600 to 800 students, student age range between 10 and 12 years, proportion of female students per classroom between 45 and 60%, proportion of male student per classroom between 40 and 55%). All of the teacher participants were females and included two first year graduates, two teachers with six to eight years of teaching experience and two teachers with eight to 12 years of teaching experience. Student participants consisted of 87 females and 72 males.

### Procedure

The study was initially designed with a before and after mixed methods approach (Cresswell, 2012) where all teachers received an intervention of professional learning around CoI and training to deliver a Year 6 unit of work designed using Bybee's (2014) 5E's instructional planning model. Given only half of the teachers in the study indicated that they chose to engage their students in CoI (confirmed in interviews with teachers, their colleagues and students), the study design evolved to assess an intervention (CoI and science unit) and comparison (unit alone) approach associating pre-unit to mid-to-late unit change in students in the 'CoI' and 'Non-CoI' groups through analysis of both qualitative and quantitative data. Qualitative data included analysis of discourse for design and inquiry verbal behaviours (Nichols et al., 2017) in small group design thinking tasks. Quantitative data consisted of measures of student achievement through pre-/post-testing and coding of tests for accurate use of scientific language (terminology) and representations. A summary of the procedure for the study is provided in Fig. 1.

### Teacher intervention: Community of philosophical inquiry

All teachers took part in two days of professional learning where they were introduced to a unit of work that culminated in a design challenge complimented with a CoI approach. A CoI on human rights for access to electricity was a way to problematize the unit content and was modelled for the teachers by showing two stimuli (a picture of a classroom in a developing country without electricity and a 5-min video describing



**Intervention phase**
- All teachers engage in 2 days professional learning around CoI and unit on electricity and energy

**Application phase**
- Pre-testing of students
- 3 teachers implement unit, 3 teacher implement CoI and unit
- Post testing of students

**Observation phase**
- Vido recording of 2 student groups per classroom as they engage in design task
- Interview teachers

**Analysis phase**
- Coding discourse for inquiry & design thinking behaviours
- Analysis of tests for representations and accurate use of scientific language

**Fig. 1** Outline of the procedure for the study

where electricity comes from and what happens with a blackout). Following the stimuli, teachers were facilitated to engage with the key ethical issue through a CoI.

The overarching questions under discussion included:

- Is electricity a basic human right? If electricity is a basic human right, then why are so many people disadvantaged?

Other substantive questions were explored to gauge a depth of understanding and foster deeper thinking about the ethics of care around the unit topic.

- Is electricity a need or a want?
- What would happen if we had no electricity?
- Is it ethical that the cost of electricity is prohibitive for many people around the world?
- What can be done about this?
- What actions can we take as individuals?
- If renewable/alternative energy sources are the answer, why are they not more accessible to everyone?
- Do we all have a responsibility to find ways to use energy more effectively?
- What might happen if no one takes responsibility for becoming ‘energy wise’?

Procedural questions were used to keep the discussion on track and to facilitate the use of thinking tools such as reason giving, seeking clarification, providing examples and counterexamples and distinction making. The discussion focussed on building a culture of respect and involved a collaborative shared dialogue concerned with making intellectual progress through thinking, reasoning and deliberative conceptual analysis. Reasoning included testing generalisations and uncovering assumptions. The reflection focussed on how the teachers engaged as a community of learners, perceptions of respect and valuing the thinking of others and the contributions made to the collaborative inquiry process.

## The unit of work

The professional learning prepared teachers with the physical resources and skills required to implement a term-long physics unit, “Powering Our World.” The unit was designed using the 5E’s instructional design model (Bybee, 2014). The Year 6 physics unit allowed a unit design for teachers to incorporate a strong emphasis on engineering with students applying their developed understanding of energy, systems and transfer throughout the school term to complete a design challenge. Teachers were resourced to challenge students to engineer a device that could generate electricity within a real-world context. Teachers were further resourced to help students explore renewable and non-renewable energy sources and to elaborate on the advantages and disadvantages of these technologies within their local context. The unit included a culminating small group assessment task to design and construct a device that is engineered to provide electricity to a third world community scenario. The design challenge is described below.

A group from the Red Cross have recently raised money and made a small pip that runs water from a local creek to a nearby third world community. Their next aim is to use this running water to provide some lighting at night. Your group’s challenge is to use the materials given and recycled materials to make a device that will generate electricity, lighting the LED.

The design challenge was set out in a series of progressive tasks appropriately scaffolded for middle years’ students. Task 1 required students to work in pairs to brainstorm what the generator would require. They were asked to explore the generator and how the LED lights up, draw a circuit diagram of the generator, connecting wires and LED. One student was to be the diagram drawer and the other would later explain how it works when the pairs come together in fours to share their ideas. Task 2 required students to work in groups of 4 to design the device and brainstorm the main features. Each student was given a role including project manager to coordinate the group work, the drafts person to help members draw sketches showing main features, a photographer to take a photo of the final design sketch, and a materials manager to discuss with the group what materials would be needed for construction of the device. Students were encouraged to perform these roles in the group but contribute ideas to the design. Task 3 required the group to draw an energy transfer diagram of the completed device design. Task 4 required students to construct the device as a group with the project manager explaining how the group was planning to go about the construction.

While the design challenge that students were asked to do at the end of the unit of work encompassed all of these tasks, in this paper we focus empirically on task 2 where students were required to work on the design of their device.

To prepare students to complete this design challenge the unit included formative tasks where they deconstructed simple electrical devices to build concepts of circuits, components and requirements. Understanding was further extended as students encountered activities of building switches, lemon battery data collection using multimeters and constructing circuits to identify energy transformations.

## Data collection and analyses

Data collection and analyses occurred across a 12-week school term with the delivery of the unit of work. Prior to and following the unit students engaged in a test of the units’ content and the competencies that the unit was designed to foster. The tests were analysed for accurate use of scientific language and representations. An analysis was conducted on the scores for accurate use of scientific language (vocabulary terms) and representations of students who completed both pre and post-tests. A total count related to the number of terms (conductor, insulator, current, charged particles, electricity, metals, potential, kinetic, electrical, turbine, generator, renewable, non-renewable, energy, fossil fuel, global warming, greenhouse gas, carbon dioxide, sustainable, resource, pollution, environment) used accurately and representations (battery, bulb, switch, circuit, solar panel, electrical design) in the student pre-tests and post–tests was investigated in the Non-CoI and CoI groups. A total test score of eight points was allocated for accurate use of scientific language and for representations.

A one-way between groups analysis of covariance (Barrett, 2011) was conducted to compare the effectiveness of two different conditions (CoI, Non-CoI) on students' use of scientific language and representations. The independent variable was the condition and the dependent variables were the post-test values for use of scientific language and representations. Students' pre-test scores for scientific language and representations were used as the covariates in this analysis. Preliminary checks were conducted to ensure that there was no violation of the assumptions of normality, linearity, homogeneity of variance, homogeneity of regression slopes, and reliable measurement of the covariate.

### Transcription and segmentation

Two small student groups per classroom conducting their power-generating device design were video-recorded for up to 40 min (group task recordings ranged from 15 to 40 min). Video recordings of 12 student groups totalled approximately 240 min. The recordings were transcribed verbatim and the transcripts were parsed into turns (Johnstone, 2007). One turn started with a student talking and ended when another student started talking or when talking ceased.

### Identifying episodes with demonstration of inquiry behaviours

We then identified episodes with demonstrations of design and inquiry verbal behaviours. These episodes were defined as two or more turns of talk initiated by a student (Johnstone, 2007) that revealed a design and/or inquiry behaviour. An episode ended when a question had been answered or a design issue had been resolved or the topic of the exchange shifted. These episodes provided the units of analysis to which the codes for the design and inquiry behaviours applied.

Episodes were coded for five inquiry behaviours (Nichols et al., 2017) as described by Cam (2006) that students demonstrate while working together to reach a common goal. The behaviours are classified as those skills utilised when critically exploring ideas and encapsulate verbal behaviour that reveals developing ideas (DI), exploring alternatives (EA), exploring key concepts (EKC), testing hypotheses (TH) and drawing conclusions (DC) (Table 1). Our previous study demonstrated that student discourse can be coded for these behaviours (Nichols et al., 2017). This is consistent with dual coding theory (Clark & Paivio, 1991) which is based on the notion that discourse can encode information about verbal behaviours such as inquiry behaviours through associative connections. Discourse and the verbal cues can reflect behavioural intentionality (Johnstone, 2007).

**Table 1** Inquiry behaviours and coded examples

| Inquiry category | Verbal behaviours | Coded examples in discourse |
|---|---|---|
| Developing Ideas | Developing ideas, building on other's suggestions and ideas, seeking clarification | S1: Where does the sand come from?<br>S2: I don't like this idea about sand<br>S1: I agree, I feel it is confusing |
| Exploring alternatives | Exploring alternative possibilities, exploring disagreement | Then we can use something else and tape it |
| Exploring key concepts | Making distinctions, uncovering criteria | It will keep the force; this will do the same but the cups will do it more efficiently |
| Testing hypotheses | Providing reasons and evidence, providing counterexamples | Like the sand pours down on the mill, the mill spins and while the mill spins there's also like a pin that's behind the mill. This was the mill [showing a ruler], there's a pin coming behind it. While the mill spins the pin spins with this [turning the ruler]. And because the pin spins this turns the turbine |
| Drawing conclusions | Modifying ideas in light of convincing evidence, making reasonable inferences | There's a pathway, a pathway between the mill, because of the force of the sand from the potential energy this will turn |

*S* Student

Discourse within episodes were also coded for demonstrations of design beahviours that are mandated by the Australian Design and Technology Curriculum (Mosely et al., 2021). Table 2 describes the behaviours or capabilities that middle years students can demonstrate during a design challenge. These include investigating and defining (T1), generating and designing (T2), producing and implementing (T3), and evaluating (T4). Examples of coding of discourse for inquiry and design behaviours are provided in Tables 1 and 2 as well as part of the results for the study.

### Interrater reliability

We determined interrater reliability scores for each of the coded behaviours using two researchers from the team across 30 percent of the episodes. Scores were compared using Cohen's kappa calculation (Cohen, 1960). Where disagreements arose, they were resolved through discussion until agreement reached 81 percent or higher.

## Results

### Exploring the design process through inquiry as discourse

Figure 2 shows an area graph of discourse across a CoI and Non-CoI group as they designed their power generating device, with shaded areas showing collective coded instances of design and inquiry verbal behaviours. These two examples were chosen as they are generally representative of the CoI and Non-CoI group discussions across the study.

This representation reveals that the CoI group tends to spend more time on the task than the Non-CoI group even though the teachers in both groups indicated that they implemented the task as was demonstrated during the professional development. In both groups the inquiry behaviours run parallel to the design behaviours. These trends were similar and consistent across all video recorded groups in the study. We further explored specific design and inquiry verbal behaviours across both the groups to see how the inquiry behaviours are drawn on through the design process.

Figure 3 shows time trends for coded design and inquiry verbal behaviours at three minute intervals for the same pair of CoI and Non-CoI groups. Each group is drawn from two separate classrooms in the same school where one teacher employed CoI and the other did not.

At this more detailed level of analysis showing the individual design and inquiry behaviours, we can see that the CoI group engages all design and all inquiry behaviours across their discussion. The Non-CoI group does not show the design behaviours around investigating and defining (T1) or producing (T3) and they also do not demonstrate the inquiry behaviour testing hypotheses (TH). These findings were consistently demonstrated across all of recorded student groups in the study.

Further, the CoI group shows a bi-phasic or cyclic recruitment of design and inquiry behaviours across their product planning discussion while the Non-CoI group does not. Specific to the CoI group, the inquiry behaviour, exploring key concepts (EKC), both initiates and concludes this discussion, with drawing conclusions (DC) and then testing hypotheses (TH) directly preceding spikes in both developing ideas (DI) and designing (T2).

In summary, the CoI group spends twice as long on task and engages more design and inquiry behaviours using standardised comparisons of proportion of all coded behaviours

**Table 2** Design skills and their coded behaviours

| Skill | Behaviours/capabilities | Examples in discourse |
|---|---|---|
| Defining | Critique, explore and investigate needs, opportunities and information for innovations<br>Evaluate social and environmental implications of innovations | My concern is with the sand here, sand flows through here. This needs to be on an angle |
| Designing | Develop/communicate ideas<br>Create change, make choices, rate options and alternatives<br>Document design ideas and possibilities focusing on high-quality designed solutions | Instead of straws we have cups here, and this will be on an angle. This is sand, but what happens to the sand after it hits the generator? We need something for it to flow |
| Producing | Apply a variety of techniques to make products designed to meet specific purposes/user needs<br>Develop capacity to select and use appropriate materials, components, tools and equipment | I have an idea cut a hole in the bottom of the bottle that we are going to use, and put a straw in it, so that the sand can rund down through the straw into the bottle where it can go through and go down and turn this |
| Evaluating | Make judgements in a design process and about the quality and effectiveness of their designed solutions<br>Determine effective ways to test and judge their designed solution | I am not certain about that. The sand getting into the straw is a bit of a problem<br>Yes, because of the pressure of the sand it can get stuck |

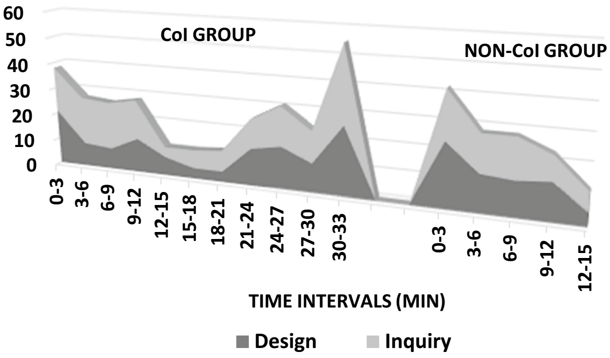


**Fig. 2** A stacked area graph showing the frequency (y-axis) of coded instances of all inquiry and design behaviours at intervals of 3 min (x-axis) drawn from the discourse of a CoI and Non-CoI group as they designed the prototype of their power generating device

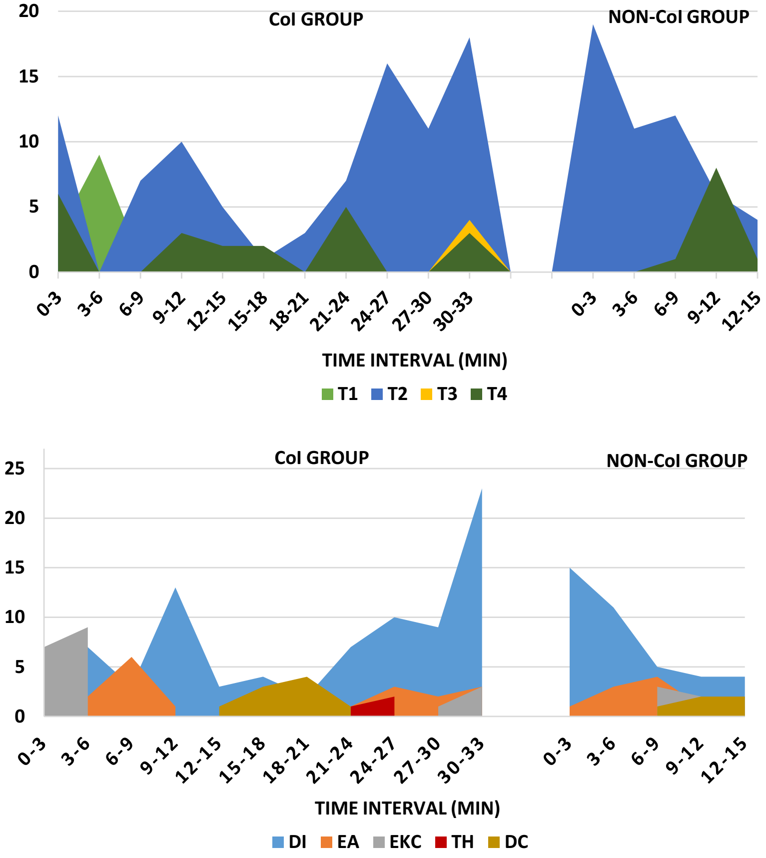


**Fig. 3** Area graphs showing the frequency (y-axes) of coded instances of design above and inquiry behaviours below across a CoI and Non-CoI group discussion of the design task at 3-min intervals (x-axes). For the designing behaviours T1 = investigating and defining, T2 = generating and designing, T3 = producing and implementing, T4 = evaluating. For the inquiry behaviours, DI = developing ideas, EA = exploring alternatives, EKC = exploring key concepts, TH = testing hypotheses and DC = drawing conclusions

per transcript text. Further, the way CoI and Non-CoI groups engage with inquiry behaviours is qualitatively different. This is illustrated with a more micro level of analysis, looking at the discourse across these two groups.

## CoI group

### Context

Students build up new ideas creatively. To work out the right operational mechanism on their design students critically reflect on how to use available resources. They finally come up with the criteria (create an angle on their turbine by anchoring it).

### St1

I have an idea, cut a hole in the bottom of the bottle that we are going to use, and put a straw in it, so that the sand can run down through the straw into the bottle where it can go through and go down and turn this. (DI, Developing ideas)

### St2

Like this; [drawing to explain] this is where the sand is and this is before the bottle, say this is the lid, it goes to the straw, and we cut a hole and this is like open and it goes through and it turns the generator. (DI. developing ideas, builds on other's suggestions and ideas; EKC, exploring key concepts)

### St3

I am not certain about that. The sand getting into the straw is a bit of a problem. (EA. exploring alternative possibilities)

### St1

Yes…because of the pressure of the sand and it can get stuck. (DI. developing ideas, EKC, exploring key concepts).

### St2

We could use a couple of (holes) at the bottom and we can just add on, add on, add on. (DC. drawing conclusions, modifies ideas; thinking creatively and critically while managing with the available resources)

### St3

It is like trial and error kind of. (DC. drawing conclusions, reflecting on intellectual conduct and design ideas)

### St1

Instead of straws we have cups here, and this will be on an angle [drawing]. This is sand [drawing], but what happens to the sand after it hits the generator? We need something for it to flow. (DC. drawing conclusions, makes reasonable inferences and develops arguments; EKC. exploring key concepts)

### St3

Will that be stable though? (DI. developing ideas, seeks clarification)

### St4

My concern is with the sand here, sand flows through here. This needs to be on an angle. (DC, drawing conclusions, reflecting on intellectual conduct; EKC, exploring key concepts)

### St1

Yes, just make this. (S. agreeing).

This student CoI group are developing deep ideas around the design of their power generating device. They provide detailed explanations of how the sand will turn the power generating device and build well on each other's ideas. They explore key concepts and probe potential problems like the sand flowing through the straw and the pressure that might disrupt flow. They solve this problem by modifying their idea, their discourse displaying critical and creative thinking as they draw conclusions. They reflect on their ideas and the way they intend to proceed with their design, their design solution is reshaped, as they restructure their thinking and ideas to replace straws with cups to help the flow. They further question their design, reflect and restructure their thinking/idea again when they come to a conclusion that the sand will flow better on an angle. The scientific language is evident in this group and used accurately. They also communicate well by drawing a representation of their design to explain their thinking.

## Non-col group

### Context

Students gather ideas from each other in order to build the power generating device.

### St3

They are normally like that they are not circles. We can find something like lunch bags. (EA. exploring alternatives)

**St2**

Yes we attach to the thing. Sand comes in an angle, then the sand drops. (EKC. exploring key concepts, critically reflects on intention)

**St3**

Sand will go on the thing and spin around [generator in hand]. (DI. developing ideas, building on others' ideas)

**St2**

Put a cup there, the pipe will be attached like that. (DI. developing ideas, building on others' ideas)

**St3**

If we put the pipe like here, a pipe this big, the pipe will go in straight (DC. draws conclusion, reflecting on intellectual conduct)

**St4**

I have a question, sand is in here, when it is pulled down is the cup going to tip? (EA. Exploring alternatives)

**St3**

We can't fix everything.

**St4**

We can put a paper plate down there and duct tape it to back up. (DI. Developing and communicating ideas)

**St3**

Are we allowed to bring things from home, like blue tack? (EA: Exploring altenatives)

**St2**

We are making it today.

This student Non-CoI group have the same idea of sand coming in on an angle. This is a good concept that they explore as well as whether to use a bag or a cup for the sand. They ask questions to test their design and consider alternatives like bringing materials in from home. They do not explore key concepts as deeply as the CoI group and there is little evidence of that restructuring of their thinking. Note that the use of scientific

**Fig. 4** The product development phase of the design process showing the bi-phasic nature of inquiry behaviours

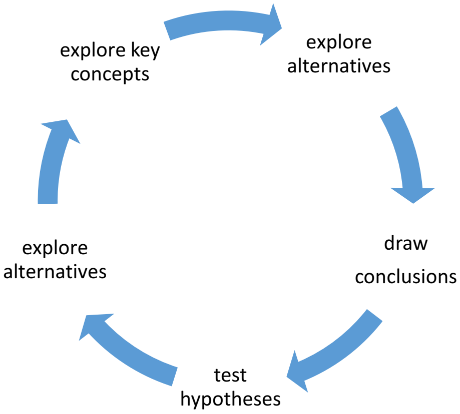


**Table 3** Comparison of pre-test mean scores and standard deviations (in parentheses) for accurate use of scientific language and representations in CoI and Non-CoI groups

| Measure | CoI (N = 65) | Non-CoI (N = 86) | $t_{149}$ | p (2-tailed) | Effect size |
|---|---|---|---|---|---|
| Scientific language | 1.32 (1.29) | 1.26 (1.30) | 0.316 | 0.753 | 0.0006 |
| Representations | 0.51 (0.53) | 0.50 (0.57) | 0.084 | 0.933 | 0.0005 |

*N* Number of students

language is not as accurate. Students use language like ‘the thing’ and ‘it’ rather than using accurate terminology. Although, as part of the task, student groups were required to have a sketch of their design, the Non-CoI groups do not draw or sketch as they plan to help explain their ideas. Their communication is limited to single statements and lacks the deeper explanatory language the CoI group utilise. This results in their low demonstrations of critical, creative and caring thinking as they do not appear to be as emotionally invested evidenced by fewer justifications, minimal collaborative discussion and ‘we can’t fix everything’.

In Fig. 4, the development of ideas for the design has a bi-phasic pattern of inquiry behaviours. The design and inquiry are restructured and reshaped as they move through the cycle of exploring key concepts, exploring alternatives, drawing conclusions, testing hypotheses and back to exploring alternatives and exploring key concepts. It is clear that there is a qualitative difference in accurate use of scientific language (terminology) and representations across the two groups as they design their power generating device. We also explored this comparison further in a moment in time context through the pre- and post-tests.

## Pre- and post-test measures of scientific language and representations

A one-way repeated measures ANOVA was conducted to compare scores on the pre-test and post-test for accurate use of scientific language and representations in Non-CoI and CoI groups. Comparison of pre-test scores are summarized in Table 3. The maximum possible score for either scientific language or representations was eight.

**Table 4** Pre-test to post-test comparison of mean scores with standard deviations (in parentheses) for accurate use of scientific language and representations in CoI and Non-CoI groups

| Group | Measure | Pre test mean (SD) | Post test mean (SD) | Wilks' lambda | F value | *p* (2-tailed) | Effect size |
|---|---|---|---|---|---|---|---|
| Non-CoI (N = 86) | Scientific language | 1.26 (1.30) | 4.52 (2.63) | 0.36 | 150.42 | 0.0005 | 0.64 |
| | Representations | 0.50 (0.57) | 4.95 (2.03) | 0.18 | 396.87 | 0.0005 | 0.82 |
| CoI (N = 65) | Scientific language | 1.32 (1.29) | 5.39 (2.44) | 0.27 | 176.07 | 0.0005 | 0.73 |
| | Representations | 0.51 (0.53) | 6.05 (1.54) | 0.08 | 757.87 | 0.0005 | 0.92 |

*N* Number of students in three- to four-person groups. *SD* standard deviation

The CoI and Non-CoI groups show no significant difference in mean pre-test scores for scientific language or representations (Table 3). The two groups were similar in abilities. Table 4 shows that the mean use of scientific terms and representations increased significantly from pre- to post-test in both the CoI and Non-CoI groups. Post hoc tests revealed that participating in a CoI elicited a significant increase in the use of scientific terms and representations from pre-test to post-test with very large effect sizes.

After adjusting for pre-test scientific language scores there was a significant difference between the two conditions in post-test scores. Similarly, after adjusting for pre-test scores for representations there was a significant difference between the two conditions in post-test scores for representations. Results are summarised in Table 5.

There was a statistically significant difference in the use of scientific language (terms) in the post-tests of the CoI and Non-CoI groups. Likewise, there was a statistically significant difference in the use of representations in the post-tests of the CoI and Non-CoI groups. Sample test question responses from both the groups exploring the accurate use of scientific language and representations are presented in Figs. 5 and 6.

Figure 5 shows that students in the CoI and Non-CoI groups were able to apply their knowledge of different energy resources to a Venn diagram, outlining the similarities and differences between two of the many sources of energy studied throughout the unit.

Answers to this question revealed that students could not only communicate the ways in which these sources were similar and different, but also provided convincing advantages and disadvantages of wind and coal energy. The CoI group tended to write more substantive responses with a more sophisticated use of scientific language.

Figure 6 shows how students responded on the post-test when they were challenged to create a new clothing product, incorporating a solar panel for a purpose of their engineering, and translating the design into a representative circuit diagram.

**Table 5** Comparison of post-test mean scores and standard deviations (in parentheses) for accurate use of scientific language and representations in CoI and Non-CoI groups

| Measure | CoI (N = 65) | Non-CoI (N = 86) | $F_{1,148}$ | p (2-tailed) | Eta squared |
|---|---|---|---|---|---|
| Scientific language | 5.38 (2.44) | 4.52 (2.63) | 4.21 | 0.042 | 0.03 |
| Representations | 6.04 (1.54) | 4.95 (2.02) | 13.06 | 0.000 | 0.10 |

*N* Number of students

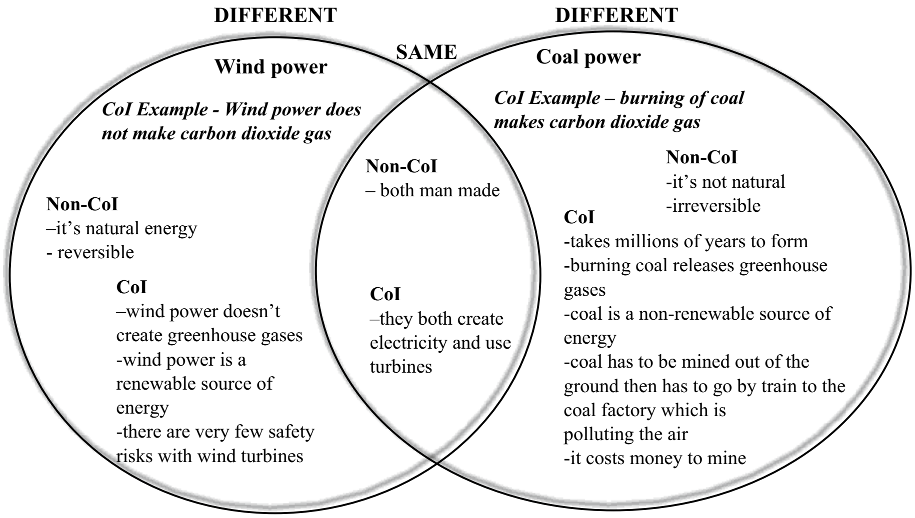


**Fig. 5** Venn diagram responses from the CoI and non CoI group to a question on the test asking how wind power and coal power are the same and different?

Students displayed a range of ideas from solar powered Christmas clothing and multi-component designs to device-charging clothing. Students in both Non-CoI and CoI groups designed accurate circuits required for creation and implementation of their ideas, with appropriate representations. However, the CoI group students demonstrated an understanding of complex series circuits to cater for several solar panels and/or components of their creative designs (Fig. 6).

## Discussion

This study shows that CoI promotes a stronger inquiry approach throughout the prototype development phase of the design thinking process resulting in restructuring or reshaping of this phase of the process and thinking/idea creation. The proposition that the design process is enhanced by pragmatist inquiry is evident in the discourse and mapping of inquiry behaviours in the CoI group. There is an intricate intersection between drawing on inquiry behaviours and more deeply engaging in design thinking practice. In design thinking, like inquiry, the meaning-making experience and interactions with objects is restructured along with thinking as the creative inquiry progresses, until a solution is reached at or the object's design meets the goals.

All students in this study when tested showed a large and significant improvement from pre-test to post-test in their accurate use of scientific language and representations associated with electricity and energy. The hypothesis that CoI can also enhance accurate use of scientific language and representation in a design context was shown by contrasting CoI and Non-CoI group post-test outcomes and small group design task discourse. The findings show that the CoI group are better or more proficient at using scientific language and representations to communicate in a design context. This suggests that CoI more significantly promotes disciplinary literacy in the context of the design process. This is consistent with a recent study (Aulia et al., 2018) that explored the impact of guided inquiry on students'

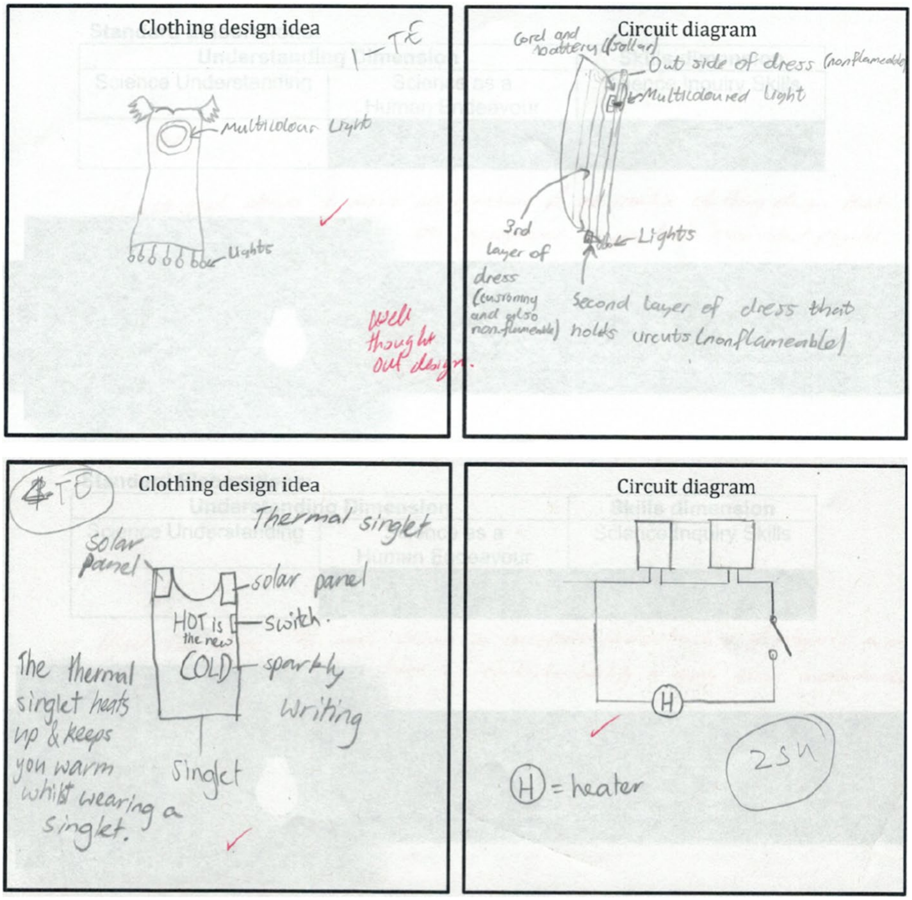


**Fig. 6** Representative response from the Non-CoI (top) and CoI (bottom) groups to a test question exploring student's clothing design ideas with representations of the design and associated circuit diagram

scientific literacy of high school students in Indonesia. Pre- post-test comparisons revealed a significant increase in scientific literacy skills in terms of the context of solubility, competence and knowledge.

The difference in scientific language and representations between the two groups in post-test outcomes was slightly significantly different with small effect sizes. However, when we look at students in these two groups and their capacity to engage in design practice and thinking, the difference in the nature of the inquiry practices, scientific language and representations across these two conditions is evident. Students that engaged with pragmatist inquiry (CoI group) showed qualitatively different discussions when designing their power generating device. They engaged holistically with all inquiry skills, their discussions were broader and deeper. They communicated with representations and accurate scientific language. This literacy advantage may have contributed to the more sophisticated explanatory language, a greater engagement in conceptual ideas and a more sustained engagement and discussion across the task. The enhanced student utterances shown in the CoI group in this study is consistent with a study of 18 primary schools in Clackmannanshire, Scotland that found students increased their level of participation in classroom discussion by half as much again after engaging in CoI (Topping & Trickey, 2007). The enhanced reasoning and explanatory language was shown to be the main reason for the longer and more sustained engagement on tasks.

This study shows that the inquiry skills acquired through engaging in CoI, provide a way for students to more deeply engage in the linguistic elements/language of design thinking and design practice, to turn the object around, critically appraise it and creatively ideate, troubleshoot and problem solve. The CoI through questioning initiated the ideation process. Students were enabled to activate their pre-conceived ideas, put it under scrutiny in the public domain or community. This process of sharing their ideas and real experiences enables a revision to their existing belief (Peirce, 1887). The coding of the discourse during a design task showed that in the conceptualising of the design, conceptualising key concepts is derived and essential to sustain the design process. In addition, in the application of these key concepts comes a deeper meaning of both science and engineering for students shown through more sophisticated use of scientific language and representation.

If we revisit the three stages of pragmatist inquiry that Dewey proposed considering the findings from this empirical study, we can see the synergies between design and pragmatist inquiry and the way pragmatist inquiry skills that are honed through the CoI mutually reinforce both the language skills and the design thinking skills. The first stage of Dewey's pragmatist inquiry is the initial problematizing of a situation in which individuals have come to experience a sense of disequilibrium. In this first stage students need to have the habits to engage with the problematizing which in this case was how they would design the device to turn the turbine and generate electricity. According to Dorst and Cross (2001) the fundamental characteristic of design cognition is the need to define the problem as well as the solution. The CoI group have already been acculturated into this mode of considering problematic situations, diverse perspectives, alternatives or multiple ways of thinking about the problem and engaging in a dialogue where they justify their ideas, build on each other's ideas and question with the view to testing generalisations and uncovering assumptions with identification of non-fallacious reasoning. We observed students in the CoI group demonstrating these kills as have other studies where primary aged students have engaged in CoI (Millett & Tapper, 2012).

The second stage of Dewey's pragmatist inquiry is whereby the problematic situation is dissected and deconstructed in order to resolve the problem. The CoI group explored key concepts and tested hypotheses more deeply than the Non- CoI group. They engaged more deeply, critically and creatively with the task. The third stage of Dewey's pragmatist inquiry is a reflective process whereby possible solutions are tested and evaluated through engagement in self-corrective reconstruction of habits. The CoI group showed greater evidence of deep reflection and reshaping of ideas, exploring many alternatives and redirecting/revisiting the design process. They continually questioned their design ideas in their reconstruction of thinking evidencing caring thinking through valuing collaborative reasoning and shared decision making. The Non- CoI group engaged in reflecting and questioning, but there was no sustained engagement or thorough exploration. The CoI group with their greater recruitment and use of pragmatist inquiry behaviours were able to shape their language and representation skills and these skills and the inquiry behaviours reinforced the design process and thinking. It is the synergies between the design thinking process and pragmatist inquiry that provide a rich context for learning progression where CoI -acquired habits mutually reinforce language skills and design thinking to a greater extent than in the absence of CoI.

We have shown empirically what Rylander (2012, p. 37) argues, "if the design process echoes Dewey's pattern of inquiry, it is because it echoes the process of conducting inquiry, whether in the context of common sense, science or art". Rylander emphasises that an important distinction of pragmatist inquiry is the notion of experience and how experience drives inquiry in the design process. Experience in the design process is embodied as ideas and ideas are embodied by language and representations which have an emotional quality to them. An idea cannot be mediated, developed or expressed until it is felt and sensed. In other words students need to care or have an emotional commitment in order to engage in idea development. Because students in the CoI group participate in a CoI that engages them emotionally in problematic and ethical issues, they develop caring thinking (Sharp, 2017) that fosters a greater engagement in the design inquiry cycle. What sets apart inquiry from design inquiry in an educational context is "the attitude and method guided by purpose and continuous experimentation" (Rylander, 2012; p. 38). According to Dewey and as represented in Fig. 3, ideas are continuously developed as the designers question their reflective premises, re-adjusting the reasoning but also opening up new ways or cycles of inquiry.

## Conclusion

This empirical study confirms and extends the proposition that, 'design thinking reflects the complex processes of inquiry and learning that designers perform in a systems context, making decisions as they proceed, often working collaboratively in teams in a social process, and speaking several languages with each other' (Dym et al., 2005, p. 104). Design thinking tasks, as modelled in this study, have what Lay Hoon (2016, p. 15) argues "greater potential for generating discussion about the form-function of scientific language than others, which in turn could deepen students' integrated understanding of the content knowledge and representational means of science". This greater proficiency in the language practices of science fosters an understanding of processes scientists, indeed designers, engage in when they build models to support an explanation of the physical world.

From an ontological perspective, design thinking and inquiry processes operate separately but interdependently. This study provides empirical evidence that the two are interdependent and progress successfully through interconnections. As students engage in the design process they call upon inquiry behaviours to reason and argue about the design, as students vacillate back and forth between design and inquiry at different times and on different levels, over time and space. The epistemological stance gives primacy to design as this is the driver or focal point presented to the students, with the CoI group having more inquiry behaviours to engage but we see this less so with the Non- CoI group. In this study, design and inquiry behaviours in the CoI group were synergistic, mutually reinforced each other, and were co-constituted. The discourse analysis showing time trends of student design and inquiry verbal behaviours across the task in the CoI group revealed that these behaviours or processes are mutually intertwined through chains of interlocking layers. In other words, if we can borrow the turn of phrase used by Putnam (2015, p. 706) to talk about the relationship between discourse and materiality, in our study, design and inquiry behaviours are intertwined "in chains of imbrication that develop over time".

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**Availability of data and materials** The data that support the findings of this study are available on request from the corresponding author KN. The data are not publicly available due to the ethical requirement to maintain research participant anonymity/privacy in video and interview data.

## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** The study has been approved by and adheres to the Guidelines of the ethical review process of The University of Queensland and the National Statement on Ethical Conduct in Human Research. The Queensland Department of Education granted approval to approach and conduct research within Queensland state schools. Ethical clearance for this study was obtained by the University of Queensland's Human Research Ethics Committee. The University of Queensland's ethical clearance process adheres with the 2018 National Health and Medical Research Council's National Statement on Ethical Conduct of Human Research, where all approved studies meet the required demonstration of the values of research merit and integrity, justice, beneficence and respect. Participants that met with a range of inclusion criteria were recruited through informed consent. These are that the teachers were teaching a Year 6 class during the period of the study and that they consented to participate in professional learning around implementation of a Year 6 unit of work on electrical energy.

**Consent to participate** Participants were provided with project information sheets and provided informed written consent to participate in the study.

**Consent for publication** All authors consent to the publication of this work.

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