Working in Groups on Practical Engineering Activities with Young Children

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Abstract
Australia has a long-standing interest in fostering innovation capabilities to drive its future prosperity. However, it has only been in recent years that an emphasis on developing these capabilities has been formally extended into the classroom through the introduction of the Australian Curriculum Technologies. In 2017, the State Government of Victoria implemented its version of this national curriculum for the Technologies domain. For educators, this recent implementation could be considered problematic, for unlike the traditions of literacy and numeracy, methods to assist classroom teachers in diagnosing developmental indicators, for applied spatial problem-solving among children appears to be lacking in the Technologies area. Without such methods of diagnosis, it can be argued that teachers may struggle to develop appropriately targeted lessons, that demand of the student, the ability to comprehend applied spatial problem-solving, such as with hands-on engineering activities. Our research aims to investigate how a child's applied spatial inferential reasoning capabilities, vary by developmental age. To answer this question, we have adopted a two-stage process. Stage One involves a pilot study testing and refining the key research instruments. Stage Two incorporates the main study involving a larger number of participants. This paper summarises early insights from a mixed-method pilot study involving 15 students (9 boys, 6 girls) from Years 3-12. Students enrolled in this study undertook one of three hands-on problem-based engineering activities categorised as simple, complicated or complex; working in small groups of three. We noted that gender makeup of the group, and age levels of participating students appeared to be variables that impacted on organisation, communication and the solution produced. These preliminary observations assisted to refine the key indicators for observing students in preparation for the main study. Key interests in this study include the student's capacity for inference-making and abstraction with respect to spatial problem-solving. A review of the relevant literature and the need for further research in spatial reasoning is discussed.

Keywords
Spatial reasoning, inferential reasoning, child development, STEM, gender education, Technacy, Technologies curriculum, innovation capabilities.

Introduction
As far back as 1996, the need to build innovation capabilities in our students was acknowledged when the Australian Science, Technology and Engineering Council's Foresight Report recommended clearly that Australia had to pursue and incorporate innovation into both the primary and secondary school curricula, with Technacy as its suggested framework (ASTEC, 1996). Technacy is defined by the Australian Standard Macquarie Dictionary as the technological equivalent to literacy and numeracy, with an emphasis on the holistic understanding and application of technology, whereby environmental and social contexts are

considered (Seemann, 2009; Technacy, 2017). The introduction of the compulsory Technologies curriculum in Victoria, Australia from Foundation to Year 10, in 2017 (State Government of Victoria, 2016), had as an objective the development of a skillset whereby students would "learn how to use technologies to create innovative solutions" that would meet both current and future needs (Victorian Curriculum and Assessment Authority [VCAA], n.d.). The Technologies curriculum demands applied spatial inferential reasoning beyond common engaging hands-on engineering activities (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2012). Of key concern to the authors of this paper, is the dearth of research literature that guides the teacher in how to identify student progression in their educational growth, when they are engaged in applied spatial inferential reasoning. Developing an evidence based approach to identify common milestone behaviours, against higher order applied spatial inferential reasoning in tackling the engineering concepts in the Australian Technologies Curriculum, offers the potential for classroom years in primary and secondary schools, to better manage learning challenges and differentiation for student centred pedagogy.

The research presented in this paper seeks to provide a preliminary insight, through early observations of a Stage One Doctoral Pilot study, into how spatial inferential reasoning capabilities vary with developmental age and the complexity of hands-on STEM activities. While the pilot research involved students from both primary and secondary schools, as part of a comparative case study, this paper will predominantly focus on students working technologically in the primary classroom. In addition, we also explore how this collaboration works in mixed gender groups. The early observations made from this pilot will inform the limited discourse on the use of instruments, specifically hands-on engineering activities, in eliciting spatial reasoning capabilities in a collaborative setting, which could assist teachers in scaffolding activities to suit students in the engineering genre of the Technologies curriculum. The Technologies curriculum is sub-divided into two subject areas: Design and Technologies; and Digital Technologies. The Technologies curriculum is a very broad area within both the Victorian and Australian Curriculum. To put in context, the Australian Curriculum provides teachers with a clear understanding of what students should learn, regardless of where in Australia they live or which school they attend (ACARA, 2016). However, under the Australian Constitution, it is the State and Territory Governments that are responsible for schools. They make decisions in the translation of the Australian Curriculum into the curriculum that is experienced by students in Foundation to Year 10. As the States and Territories have not agreed to common curriculum and assessment in Years 11 and 12, each jurisdiction has devised its own. Since this paper will focus on the capability of students to abstract and infer in the engineering genre of the Technologies curriculum, the Design and Technologies subject will be the focus.

Spatial inferencing in middle childhood

According to the National Research Council (1984), middle childhood is a period between the ages of 6 and 12. This is a time of tremendous developmental growth, which spans the six main developmental categories of physical and brain development; language development; cognitive development; social development; emotional development; and moral development (Duchesne & McMaugh, 2019). The ability to "reason through scenarios" is a noted observation in middle childhood (Knight & Lee, 2008, p. 146).

Abstraction and spatial inferential reasoning are key to imagining a way for engineering concepts to work in real time applications (Contero, Naya, Company, & Saorin, 2006). Spatial inferential reasoning is seen as being necessary for developing the capability in students of thinking and acting as innovators in the engineering genre of the Technologies curriculum (Kell, Lubinski, Benbow, & Steiger, 2013; Khine, 2017). A working definition of spatial inferential reasoning is taken as the “mental processes of representing, analysing, and drawing inferences from spatial relations” (Uttal, Miller, & Newcombe, 2013, p. 367). For example, consider an individual who observes an engineering structure such as a machine or device of some sort and, is able to rotate mentally that three-dimensional object, or can visualise the machine working in three-dimensions. Such an individual is demonstrating a spatial skill; they are forming abstract inferences of how they imagine the object or mechanism to work and be positioned in relative terms in space.

According to Piaget’s model of cognitive development, a child’s intellectual development progresses through a series of stages that are characterised by qualitatively different cognitive processes (Goswami, 1998). As abstraction and spatial inferential reasoning are dependent on cognitive ability, the work of Piaget provides a foundation to this study, with student participants selected from two distinct stages of Piaget’s framework: concrete operations; and formal operations. For the purpose of the Stage One Pilot study, students were randomly selected from three cohort groups: Years 3 and 4; Years 7 and 8; and Years 10 to 12. Focusing on the junior group drawn from students in Years 3 and 4, with an age range of 7 to 9 years of age, these students are considered in middle childhood and progressing from the ability to think about concrete realities to more formal operational reasoning where they think about abstract possibilities. According to Piaget’s stage model, these students should be showing some early signs of the ability to abstract and infer. However, this can be considered a contentious point, as Gopnik (2012) argues that contrary to Piaget’s view, children exhibit elements of abstract reasoning, albeit “basic inductive processes of science” (p. 1623) that are typical of scientific experimentation.

Collaboration between students

Often engineering and STEM work is conducted in a team, and the ability to communicate abstract ideas is essential. Developing innovation capabilities in schools goes beyond simply transmitting knowledge. As learning is a complex social process, it requires students to work collaboratively across multiple contexts (Vygotsky, 1978). Not surprisingly, an increasing number of educational jurisdictions are including collaboration as a required skill in their curriculum (Tarbutton, 2018). Social communication, and how this can progress cognitive abstraction, is the second of the two qualities that is examined in this pilot study and the subsequent main study.

Children in middle childhood are still developing the skill of working collaboratively (Baines, Blatchford, & Kutnick, 2003). A common scenario can be observed where children are working alongside each other at a table, but with no clear evidence of the children exchanging and sorting their ideas to develop a logical solution to meet the objectives of a group task they have been given (Baines, Blatchford, & Kutnick, 2003; Kutnick & Blatchford, 2014). With increasing maturity and further development of their social skills, the nature and the level of social interaction becomes more sophisticated and complex. As Rusk and Rønning (2020) have observed, there remains scope for further research involving group-work, such as the social organisation of groups, and the skills needed for students to engage effectively in group-work, through sharing and trading ideas.

The notion of parallel play has been reported in the early pre-school years, where children can be observed playing side-by-side but with no real interaction or cooperation between the children (Bakeman & Brownlee, 1980; Howes & Matheson, 1992). As the child continues to develop, this individual play is increasingly replaced by one that is more cooperative and social (Bakeman & Brownlee, 1980). Of interest to this study is therefore the nature and level of interaction between children working technologically in small groups in the primary classroom. One hypothesis is that younger students (i.e. the junior cohort) will not exhibit the level of trading of ideas in a group situation, as is expected with the older students (i.e. the senior cohort).

Children and self-esteem

In any problem-solving activity, negative emotions could be experienced if students are given a task that is beyond what Vygotsky (1978) referred to as their zone of proximal development. Logically, this would be expected to impact on a student's ability to function (Boekaerts, 1993). It would have an adverse impact on the student's sense of self, such as their self-esteem. In an Engineering class, this can result in the student throwing their hands up in despair; possibly resulting in a feeling or sense of failure, as would be suggested by the work of Erikson (1968). Table 1 provides a comparison of three developmental indicators, including Erikson's psychosocial stage model for our Junior Group of students taken from Year 3 and Year 4, and the Senior Group taken from Years 10 to 12.

Table 1: Comparison of three developmental indicators

	Years 3 and 4 (Junior Group)	Years 10 to 12 (Senior Group)
Piaget's cognitive development	Students can mentally manipulate and think logically about objects, and see from another person's point of view	Students can think abstractly, develop hypotheses, and use a systematic approach to solve problems
Social interaction	Developing	Relatively advanced / students trading ideas
Erikson's stage of psychosocial crisis	Industry vs Inferiority	Identity vs Role confusion

Self-esteem describes our sense of worth as a person (Kille & Wood, 2012) and it is an important element in children's overall wellbeing (Orth & Robins, 2013). Closely associated to self-esteem is the concept of self-efficacy, which is concerned with an individual's belief about their ability to perform a task successfully (Bandura, 1994). For this reason, self-efficacy is often referred to as our can do attitude of self, and is influential in how we feel, think and act (Bandura, 1994). Potentially we can damage students' self-efficacy, so students go from a can do attitude to a can't do attitude or developing feelings of I'm dumb. A feeling of inferiority develops when students experience a negative event in the classroom, which can then lead to feelings of self-doubt or being a failure (Erikson, 1968). Teachers play an important role in reinforcing a sense of competence in primary school students. However, in the Technologies curriculum, hands-on engineering activities can be hit or miss, as the experience of a teacher may determine whether a suitably challenging activity is implemented in the classroom (Crismond, 2013). When developing hands-on engineering tasks for students, it is important that they be provided with appropriate challenges that are realistic; otherwise, the potential exists for students to feel like failures (Martin, 2010).

Gender differences

Developmental milestones are not only dependent on age, as gender also plays a role. This is evident from neuroscience research, which reports that the cerebral cortex, cerebellum and the corpus callosum develop at different rates in boys compared with girls. For instance, the cerebral cortex reaches maximum size in boys by age 15, compared with age 11 for girls (Giedd & Rapoport, 2010). A comparison of the corpus callosum (which connects the two hemispheres of the brain) is reportedly thinner in boys compared to girls of the same age (Francis, 2006). This is important to note, as the cerebral cortex is believed to play a significant role in cognition, perception, language and executive function (Lerner & Schenk, 2014), whereas the corpus callosum is responsible for integrating key motor, sensory and cognitive functions across the two hemispheres (Francis, 2006). For this reason, the role of gender is considered important when examining key cognitive functions such as spatial inferential reasoning, creativity, critical thinking and communication. This is especially relevant in light of research, which suggests that teachers are often unprepared to address the number of gender-related differences and issues that are found in the classroom (Major & Santoro, 2014).

Research Questions and Methodology

The Stage One Pilot project, which is the basis of this paper, was conducted to test, refine and develop the key indicators for observing students and their ability to reason in a spatial inferential manner. The revised indicators and methodology were an outcome of this pilot study, and will be tested in the second phase of this study involving a larger group of participants.
For the pilot study, the researchers set out to answer the following two questions:
Can the hands-on engineering/STEM activities developed, elicit a demonstrable difference in spatial reasoning between the three groups of junior school, middle school, and senior school students?

What impact does gender have on group structure, task progress and task completion when completing hands-on engineering activities?
A small-scale mixed-method comparative case study involving three different cohort groups from the same co-educational Early Learning to Year 12 independent inner-city school, informed this study. A summary of the groups is presented in Table 2.

Table 2: The three student cohort groups that formed the Stage One Pilot study

Junior Group	Middle Group	Senior Group
Years 3 and 4	Years 6 and 7	Years 10 – 12
Age range 7 to 9	Age range 10 to 12	Age range 15 to 18
Six participants	Six participants	Three participants

Students from within each cohort level (i.e. junior, middle and senior) were randomly assigned to a small mixed-gender group comprising of three students for completing one hands-on engineering activity. Five groups in total formed the basis of this pilot study, with two groups from junior school, two from middle school, and one from senior school. Each group, of exactly three students, undertook one hands-on engineering challenge, with each group of three randomly assigned to complete one of three engineering challenges. The three engineering challenges were of varying level of complexity: simple, complicated or complex as determined by the researchers. These challenges are shown in Figure 1. The three hands-on engineering activities identified for this research are all practical tasks that are well suited to engaging students with hands-on problem solving in the Design and Technologies (Engineering) domain of the Victorian Curriculum.

Students were video- and audio-recorded. They were asked to think aloud to capture deeper insights into their strategies and logical thought processes. As the students built their simple, complicated or complex machine, non-verbal behaviour and cues were captured (Cohen, Manion, & Morrison, 2011) in addition to their verbal reasoning via the think aloud approach. The product of each activity was a machine that had been built according to the design brief or a set of provided instructions. This then became a physical artefact. The students' ability to abstract in building the machines included quality of the artefact and meeting the design brief. The quality of the artefact was assessed as either a viable solution (i.e. the machine worked as expected), or a non-viable solution (i.e. the machine did not function as intended). Other measures observed/captured included: the level and quality of the social interaction within the group, and the nature of verbal and non-verbal communication during the activity. Any difficulties that students were experiencing, such as struggling to meet the objective of their hands-on task, could manifest in a change of attitude toward the task and/or a change in their behaviour (Greene, 2018). This could provide insight into Erikson's psychosocial model from a Technologies perspective.

Simple Challenge	**Complicated Challenge**	**Complex Challenge**
Windmill 	Tower Crane 	Steerable Boat 
Complete set of instructions given, with the precise number of parts included in the kit	Pre-determined number of steps missing from the set of instructions; extra parts included	Design brief given with choice of components; but one key component not evident

Figure 1: The three hands-on engineering activities of varying complexity

Collecting data through the kits

In developing the hands-on diagnostic engineering kits, several factors were considered, the most important of these being:

- student safety;
- time required for students to attempt/complete the activity (to minimise amount of time that students are withdrawn from classes); and
- cost of hands-on resources.

With the comparative case study involving young students from Years 3 and 4, student safety was paramount. For this reason, the simple and complicated hands-on activities adopted LEGO's use of interconnecting plastic components. The simple and complicated kits are shown in Figure 1. For the complex task, students were provided with a kit of parts that included pre-assembled components, such as small alligator clips soldered to ends of wires, which in turn were soldered to motor terminals, solar panels and battery packs. This use of pre-assembled components reduced the number of tools that students needed to those readily available in the school classroom (e.g. scissors) and thus decreasing the risks.

Complexity levels presented by the kits

Complexity level: Simple

With respect to cognitive demand on inference making, this task is simple as the solution or end goal is given to the students. There is little that students have to imagine. The students are given the precise number of parts required to construct a machine, with a complete set of instructions provided. Each step is given in a mostly one-to-one mapping towards the solution. Thus, there is low demand to imagine the step, and no demand to imagine a working solution.

Complexity level: Complicated

In the complicated activity, more demand is placed on imagining the steps to a working solution. While students are provided the solution (or endpoint) in the form of a two-dimensional diagram, they are given an incomplete set of instructions, with several sub-steps deliberately removed. An intended further complication is that students are provided with more parts than needed to construct the machine. With several sub-steps missing, students are required to bridge the gaps, which demand some imagination to join either side of the missing steps. Success of this challenge is determined by whether or not the machine works as it was intended.

Complexity level: Complex

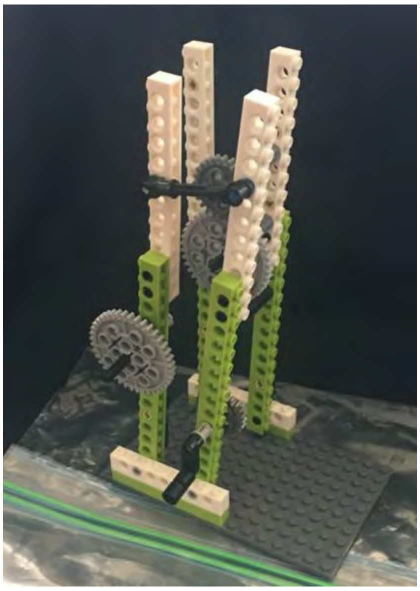
Unlike the simple or complicated activity, in this complex task the solution is not provided, however it is described in the form of a design brief. At least one solution will work. There are a number of abstractions that students need to make, such as, how the model boat will float or how it can be controlled remotely. Additionally, there will be other design decisions requiring students to draw upon their life experiences.

Analysis and Discussion of Early Observations

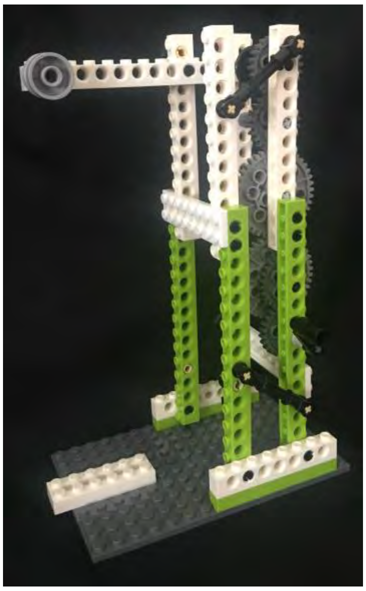
A summary of key observations from the Pilot Study with some detailed commentary are provided below.

Suitability of the hands-on research instruments

The research instruments developed in the form of three hands-on engineering activities of varying complexity and tested in this pilot study have the potential to elicit cognitive and social differences between the different aged cohort groups. In undertaking the complicated activity, junior students were observed to be working in parallel, with limited trading of ideas and little distribution of sub-tasks among this group of three, which resulted in a model that was partially constructed (i.e. unsuccessful build resulted). In contrast, the senior students approached the complicated task as a ‘joint endeavour’, working cooperatively to produce a machine that worked as intended and which satisfied the challenge requirements (i.e. successful build resulted). Figure 2 shows the junior group’s attempt to build the complicated Tower Crane, which placed cognitive demand on the students to imagine the steps to a working solution given several construction steps were missing.



(a) Junior Group 1 end-result for Tower Crane



(b) Tower Crane as it should look

Figure 2: Complicated task – Tower Crane

Social non-task related discussion was a regular feature in the junior groups, with the boys prone to distraction that is more frequent and for longer, than the girls. Distraction within the middle-school students was minimal, with the senior students showing no inattention to the challenge task. One particular observation of note, which emanated from the boy-dominated junior group, occurred when one of the two boys stated “we're smarter in LEGO” to which the young girl retorted “we’re [girls] smarter in English”. This stereotypical discussion about contrasting gender abilities is similar to that reported by Bergin et al. (2018). This raises implications for teachers on how to handle gender stereotyping at the primary school level, especially in light of the under-representation of women in STEM-related courses (i.e. senior high school and university) and employment in STEM careers such as engineering (Australian Academy of Science, 2019; Colette & Marjolaine, 2017; Kricorian, Seu, Lopez, Ureta, & Equils, 2020).

(a) Middle Group 1 and their completed Windmill

(b) Middle Group 2 and a partially built boat

Figure 3: The two artefacts produced by the middle groups

While the simple, complicated and complex activities seemed appropriate for eliciting spatial reasoning and levels of communication in a group setting, the question remained of how much time is reasonable to conduct these experiments without compromising the quality of data collection. As these activities were conducted as a research experiment, a nominal amount of time was determined by the researchers to ensure minimal impact on schools. The time allocated for each of the three activities - 15 minutes for simple; 20 minutes for complicated and 25 minutes for complex was insufficient for all five groups. Additional time was given to each group, with only one of the two middle group completing the construction of their machine. They were given an additional seven minutes to complete the simple Windmill machine, as shown in Figure 3. The senior group completed their complicated machine, though were given an additional four minutes. Extra time will need to be provided to participants in the main study.

Gender impact on group structure and collaboration

Girls took the lead role in both junior groups when solving the engineering problems, unlike the middle and senior groups where the girls were content to sit back and allow the boys to take the lead. The observations with the middle and senior groups is not surprising in light of the work by Major and Santoro (2014) who suggested that girls are “characterised by compliance, sociability, caring and empathy” (p.60) to solve problems. Further study is required in this area and will be a focus in the second phase of this study.

Another gender-related observation relates to the girl-dominated junior group (i.e. 2 girls, 1 boy). The girls exhibited a greater tendency to work collaboratively through communicating ideas and nominating individual tasks for each member to undertake. Conversely, the boy-dominated junior group (i.e. 1 girl, 2 boys) were prone to frequent distraction, despite the best efforts of the lone girl who provided words of encouragement and reminded the two boys that they were being assessed as a team. This comparison is shown in Table 3.

Table 3: Comparison of the two junior groups

Junior Group 1 (complicated task)	Junior Group 2 (complex task)
2 boys, 1 girl girl took lead role students were working primarily in parallel, with little evidence of trading/sharing ideas boys were distracted on many occasions, but as model construction progressed, they settled and focused on building girl attempted to provide moral support to the boys, but was concerned about failing at the task artefact produced shown in Figure 2 did not work as intended	1 boy, 2 girls girl took lead role some evidence of trading/sharing of ideas was present boy did as instructed by lead girl, but was distracted on a few occasions by the presence of the camera girls stayed on task throughout, though some social (non-task) commentary was present artefact produced met one of the three criteria (i.e. powered by electricity, but boat did not float and was not steerable)

The contrasting observations of the two junior groups raised the question: does the composition of having two girls in the group lead to effective collaboration amongst the team? These observations highlight the work of Rusk and Rønning (2020) and support their argument that further research is required to tease out the finer workings of these types of relationships in group activities. The impact of gender on group structure is a consideration that has been previously flagged by researchers, such as Kutnick and Blatchford (2014). Additionally, the argument that students need to develop a set of skills for effective, cooperative and collaborative work when students engage in group-based tasks (Kershner, Warwick, Mercer, & Kleine Staarman, 2014; Looijenga, Klapwijk, & De Vries, 2016) has also been a topic of research over the last few years.

Failure and self-esteem

The only girl in Junior Group 1 undertaking the complicated challenge remarked that she "finally failed a test". This was not the intention of the complicated activity; however, it is a reminder of the importance students place on their self-esteem and self-efficacy. Ensuring that activities are not beyond a student's developmental ability or beyond the zone of proximal development when activities are group-based with peers that are more knowledgeable, should help alleviate situations where students could develop the mind-set of not being smart enough. In this situation, teachers play a critical role, by providing encouragement, task scaffolding, and setting appropriate challenges in the classroom, all which can help build a sense of competence. While Orth and Robins (2014) indicate that self-esteem generally improves from adolescence to middle adulthood, the case is not clear with younger children, with some evidence identifying a number of factors that can contribute to a decline in a child's self-esteem as they enter middle childhood (Harter, 2012).

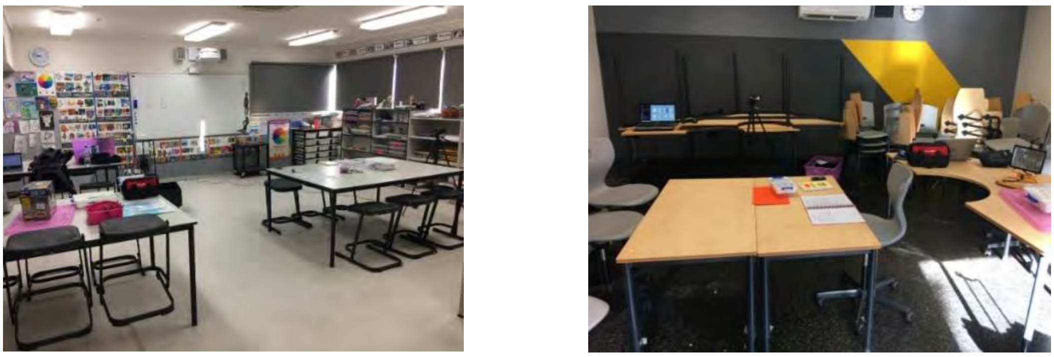
The girl in Junior Group 1 believed that she was hamstrung by her two male peers and their inability or desire to work effectively as a team. She believed that she had the capability to complete the complicated task if she had been able to complete the task on her own. She was the only one in the group concerned that some steps were missing, whereas the two boys were adamant that nothing was amiss and that they could complete the challenge. This observation, albeit from a pilot study, lends support to the arguments expressed by other researchers that students need to be taught to work collaboratively (Kutnick & Blatchford, 2014; Rusk & Rønning, 2020).

This study also flags an interesting possibility that girls possess a greater awareness for finer details. This could be attributed to their cognitive and brain development relative to boys of similar age. The main study will seek to investigate this dimension of spatial activity in both individual and group-work settings.

This observation further highlights a key dimension to engineering activities, both in the classroom and in the real world, that failure is a "normative condition in engineering" (Lottero-Perdue & Parry, 2017, p. 49). Failure is therefore considered an important aspect of teaching Technologies subjects such as Engineering. It is necessary for students to test and evaluate whether their design criteria have been met (Lottero-Perdue & Parry, 2017). The Framework for K–12 Science Education in the USA has incorporated failure analysis into their curriculum when teaching engineering concepts to primary school students (National Research Council, 2012). Such an emphasis is missing from the Technologies curriculum in Australian schools. Regardless, teachers should be encouraged to incorporate failure analysis within their teaching discipline.

Classroom effect on design decisions

It is important to consider the layout of the classroom environment when undertaking hands-on activities. Two junior groups were located in an Art Room which encouraged a level of experimentation in completing the complex task, with students actively considering materials commonly found in this type of room (e.g. cork) that would help satisfy the design brief (i.e. boat needed to float). A similar such level of experimentation was not evident in the traditional room setting. The two rooms used are shown in Figure 4. Incidentally, it was noticed that student distraction was minimal in the traditional room setting; however, this was not the case in the Art Room where the boys from the two junior groups were distracted most often.



(a) The 'art' room (junior groups)

(b) The 'utility' room (middle/senior groups)

Figure 4: Classroom environment for student observations

Further research in spatial abilities

While this study draws upon the work of Piaget and his stage model of cognitive development, the work of Gopnik and Wellman (Gopnik, 2012; Gopnik & Wellman, 2012) in investigating the spatial abilities of children needs to be considered, as the development of abstraction and spatial reasoning is not clear cut. Students that might be identified as possessing high spatial ability are not being recognised, as they do not necessarily demonstrate high ability in verbal or mathematical reasoning (Webb, Lubinski, & Benbow, 2007). Spatial abilities develop from birth (Mathewson, 1999), with evidence these abilities are “malleable and can be improved with interventions, enrichment and training activities” (Khine, 2017, p. 3). Nadelson, Seifert, Moll, and Coats (2012) argue that schools should place a greater emphasis on STEM education in the early years to help build student capability in the technology and engineering domains of the curriculum and to help build spatial abilities.

Conclusion

This Pilot Study provided a number of useful insights that are important for our preparations for the main research study. The research instruments used, specifically the simple, complicated, and complex hands-on engineering activities demonstrated their potential to elicit noticeable differences in the spatial reasoning between the junior students and the senior students. Spatial inference making and abstractions improved with developmental age.

Gender in a group setting emerged to be a variable that impacted on the organisation of individual sub-tasks within a challenge and the communication throughout the activity. This will be explored in greater detail by the main study, in particular, the observation of girls taking a central role in allocating tasks and driving the group’s decision-making process, in contrast to girls taking a ‘back-seat’ role when in high school.

References

Australian Academy of Science. (2019). Women in STEM decadal plan. Retrieved from https://www.science.org.au/files/userfiles/support/reports-and-plans/2019/gender-diversity-stem/women-in-STEM-decadal-plan-final.pdf.

Australian Curriculum, Assessment and Reporting Authority [ACARA]. (2012). The shape of the Australian Curriculum: Technologies. Retrieved from https://docs.acara.edu.au/resources/Shape_of_the_Australian_Curriculum_-_Technologies_-_August_2012.pdf.

Australian Curriculum, Assessment and Reporting Authority [ACARA]. (2016). Curriculum. Retrieved from https://www.acara.edu.au/curriculum.

Australian Science, Technology and Engineering Council [ASTEC]. (1996). Developing long-term strategies for science and technology in Australia - findings of the study: Matching science and technology to future needs 2010. Canberra, Australia: Australian Government Publishing Service.

Baines, E., Blatchford, P., & Kutnick, P. (2003). Changes in grouping practices over primary and secondary school. International Journal of Educational Research, 39(1-2), 9-34. doi:10.1016/S0883-0355(03)00071-5

Bakeman, R., & Brownlee, J. R. (1980). The strategic use of parallel play: A sequential analysis. Child Development, 51(3), 873-878. doi:10.2307/1129476

Bandura, A. (1994). Self-efficacy. In V. S. Ramachaudran (Ed.), Encyclopedia of human behavior (Vol. 4, pp. 71-81). San Diego, CA: Academic Press.

Bergin, C. C., Bergin, D. A., Walker, S., Daniel, G., Fenton, A., & Subban, P. (2018). Child and adolescent development for educators. South Melbourne, Australia: Cengage.

Boekaerts, M. (1993). Being concerned with well-being and with learning. Educational Psychologist, 28(2), 149-167. doi:10.1207/s15326985ep2802_4
Cohen, L., Manion, L., & Morrison, K. (2011). Research methods in education (7th ed.). Abingdon, England: Routledge.
Colette, A., & Marjolaine, C. (2017). Perception by French students of the gendered nature of material artifacts studied in technology education. International Journal of Technology and Design Education, 27(1), 1-18. doi:10.1007/s10798-015-9329-9
Contero, M., Naya, F., Company, P., & Saorin, J. L. (2006). Learning support tools for developing spatial abilities in engineering design. International Journal of Engineering Education, 22(3), 470-477.
Crismond, D. (2013). Design practices and misconceptions. The Science Teacher, 80(1), 50-54.
Duchesne & McMaugh (2019). Educational psychology for learning and teaching (6th ed.). South Melbourne, Australia: Cengage.
Erikson, E. H. (1968). Identity: Youth and crisis. New York, NY: Norton and Co.
Francis, B. (2006). The nature of gender. In C. Skelton, B. Francis, & L. Smulyan (Eds.), The SAGE handbook of gender and education (pp. 7-17). London, England: SAGE.
Giedd, J. N., & Rapoport, J. L. (2010). Structural MRI of pediatric brain development: What have we learned and where are we going? Neuron, 67(5), 728-734. doi:10.1016/j.neuron.2010.08.040
Gopnik, A. (2012). Scientific thinking in young children: Theoretical advances, empirical research, and policy implications. Science, 337(6102), 1623-1627. doi:10.1126/science.1223416
Gopnik, A., & Wellman, H. M. (2012). Reconstructing constructivism: Causal models, Bayesian learning mechanisms, and the theory theory. Psychological Bulletin, 138(6), 1085-1108. doi:10.1037/a0028044
Goswami, U. (1998). Cognition in children. London, England: Taylor & Francis Group.
Greene, R. W. (2018). Transforming school discipline: Shifting from power and control to collaboration and problem solving. Childhood Education, 94(4), 22-27. doi:10.1080/00094056.2018.1494430
Harter, S. (2012). The construction of the self: Developmental and sociocultural foundations (2nd ed.). New York, NY: The Guilford Press.
Howes, C., & Matheson, C. C. (1992). Sequences in the development of competent play with peers: Social and social pretend play. Developmental Psychology, 28(5), 961-974. doi:10.1037/0012-1649.28.5.961
Kell, H. J., Lubinski, D., Benbow, C. P., & Steiger, J. H. (2013). Creativity and technical innovation: Spatial ability's unique role. Psychological Science, 24(9), 1831-1836. doi: 10.1177/0956797613478615
Kershner, R., Warwick, P., Mercer, N., & Kleine Staarman, J. (2014). Primary children's management of themselves and others in collaborative group work: 'Sometimes it takes patience…'. Education 3-13, 42(2), 201-216. doi:10.1080/03004279.2012.670255
Khine, M. S. (2017). Spatial cognition: Key to STEM success. In M. S. Khine (Ed.), Visual-spatial ability in STEM education: Transforming research into practice (pp. 3-8). Cham, Switzerland: Springer International.
Kille, D. R., & Wood, J. V. (2012). Self-esteem. In V. S. Ramachaudran (Ed.), Encyclopedia of human behavior (pp. 321-327). London, England: Elsevier.
Knight, E. B., & Lee, E. L. (2008). A guide to teaching developmental psychology. Oxford, England: Wiley-Blackwell.

Kricorian, K., Seu, M., Lopez, D., Ureta, E., & Equils, O. (2020). Factors influencing participation of underrepresented students in STEM fields: matched mentors and mindsets. International Journal of STEM Education, 7(1), 1-9. doi:10.1186/s40594-020-00219-2

Kutnick, P., & Blatchford, P. (2014). Effective group work in primary school classrooms: The SPRinG Approach. Dordrecht, The Netherlands: Springer.

Lerner, A., & Schenk, C. (2014). Cerebral cortex. Encyclopedia of the Neurological Sciences, 1, 662-671. doi:10.1016/B978-0-12-385157-4.01132-5

Looijenga, A., Klapwijk, R., & De Vries, M. J. (2016). Groundwork: Preparing an effective basis for communication and shared learning in design and technology education. Design and Technology Education: An International Journal, 21(3), 41-50.

Lottero-Perdue, P. S., & Parry, E. A. (2017). Perspectives on failure in the classroom by elementary teachers new to teaching engineering. Journal of Pre-College Engineering Education Research, 7(1), 47-67. doi:10.7771/2157-9288.1158

Major, J., & Santoro, N. (2014). 'Sensible girls' and 'silly boys': What do teachers need to know about gender? The Australian Educational Researcher, 41(1), 59-72. doi:10.1007/s13384-013-0121-0

Martin, A. (2010). Building classroom success: Eliminating academic fear and failure. London, England: Continuum International.

Mathewson, J. H. (1999). Visual-spatial thinking: An aspect of science overlooked by educators. Science Education, 83(1), 33-54. doi:10.1002/(SICI)1098-237X(199901)83:1<33::AID-SCE2>3.0.CO;2-Z

Nadelson, L. S., Seifert, A., Moll, A. J., & Coats, B. (2012). i-STEM summer institute: An integrated approach to teacher professional development in STEM. Journal of STEM Education: Innovation and Outreach, 13(2), 69-83.

National Research Council. (1984). Development during middle childhood: The years from six to twelve. Washington, DC: National Academy Press.

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, DC: The National Academies Press.

Orth, U., & Robins, R. W. (2013). Understanding the link between low self-esteem and depression. Current Directions in Psychological Science, 22(6), 455-460. doi:10.1177/0963721413492763

Orth, U., & Robins, R. W. (2014). The development of self-esteem. Current Directions in Psychological Science, 23(5), 381-387. doi:10.1177/0963721414547414

Rusk, F., & Rønning, W. (2020). Group work as an arena for learning in STEM education: Negotiations of epistemic relationships. Education Inquiry, 11(1), 36-53. doi:10.1080/20004508.2019.1638194

Seemann, K. (2009). Technacy Education: Understanding cross-cultural technological practice. In J. Fien, R. Maclean, & M.-G. Park (Eds.), Work, learning and sustainable development (pp. 117-131). Dordrecht, The Netherlands: Springer.

State Government of Victoria. (2016). Introducing the digital technologies curriculum. Retrieved from https://cpb-ap-se2.wpmucdn.com/global2.vic.edu.au/dist/e/29837/files/2018/02/11315-DEECD-Digitech-Curriculum-FA4-interactive-1zrbr67.pdf.

Tarbutton, T. (2018). Leveraging 21st century learning and technology to create caring diverse classroom cultures. Multicultural Education, 25(2), 4-6.

Technacy. (2017). In S. Butler (Ed.), Macquarie dictionary (7th ed.). Retrieved from https://search.credoreference.com/content/entry/macqdict/technacy/0.

Uttal, D. H., Miller, D. I., & Newcombe, N. S. (2013). Exploring and enhancing spatial thinking: Links to achievement in science, technology, engineering, and mathematics? Current Directions in Psychological Science, 22(5), 367-373. doi:10.1177/0963721413484756

Victorian Curriculum and Assessment Authority [VCAA]. (n.d.). Victorian Curriculum Foundation-10: Technologies – about the technologies. Retrieved from https://victoriancurriculum.vcaa.vic.edu.au/technologies/introduction/about-the-technologies.

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Cambridge, MA: Harvard University Press.

Webb, R. M., Lubinski, D., & Benbow, C. P. (2007). Spatial ability: A neglected dimension in talent searches for intellectually precocious youth. Journal of Educational Psychology, 99(2), 397-420. doi:10.1037/0022-0663.99.2.397