Spatial Skills Development for Industrial Training

DECEMBER 2021

First Polymer Training Skillnet

TUS Midlands Midwest

Polymer Technology Ireland Ibec

Table of Contents

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Holding pressure
Injection

Foreword

Polymer Technology Ireland and First Polymer Training Skillnet have always taken a progressive and innovative view of new ways of learning and improving a trainee's experience on our programmes. While we had an awareness of the benefits of spatial skills in engineering and in everyday life; we were not aware of its proven impact on performance across a range of technical disciplines and also on retention in long term education programmes. While this had been previously studied both nationally and internationally with 2nd and 3rd level students, it had never been looked at in an industrial setting, to assess the potential benefits to both individuals and their employers.

We welcome this report and would like to acknowledge the significant body of work undertaken by Technological University of the Shannon, Midlands Midwest. We would like to thank all of the participants from our network who took part in the study and their employers for facilitating them. Finally, we would like to thank Skillnet Ireland for their funding and support of this research.

Mark McAuley,
Director of Polymer Technology Ireland

Continuous professional development (CPD) is a combination of approaches, ideas and techniques focused on reskilling and upskilling initiatives that individuals or organisations may undertake to respond to emerging future skills needs and ensure relevance in an ever-changing industrial landscape. By its very nature, CPD can be delivered in a variety of settings, by different kinds of educators for differing lengths of time, with varying intensities and is an absolutely vital component in preparing society for the jobs of the future. Understanding the effectiveness of training approaches and how the impact on the learner may be facilitated is critical to ensuring that training interventions are appropriate, impactful and efficient. The First Polymer Training Skillnet has a long history of providing effective training support for the Irish polymer sector, with many trainees stemming from sectors reliant on advanced manufacturing approaches to remain competitive. This report, commissioned by First Polymer Training Skillnet as part of their own agenda for measuring and optimising training effectiveness, outlines the findings of a focused programme of research completed to ascertain if cognitive development interventions could complement, augment or enhance their current applied training practices.

Dr. Sean Lyons,
Dean of Faculty of Engineering and Informatics,
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Executive Summary

This report outlines the findings, observations, discussions and concluding recommendations of a research study conducted to explore the role that spatial skills training can play in increasing the effectiveness, efficiency and experiential value of industrial training interventions. Spatial skills development has continually been shown to be an effective means of improving the retention, success and future career progression of early-stage undergraduate engineering education students.

The Theoretical Background section of this report outlines a working definition for spatial ability and empirical evidence which highlights the association between spatial abilities and success in engineering education. However, minimal investigation has been carried out to explore if such spatial skills development could be beneficial for adult learners in technical and engineering roles in industry, who are undertaking continuous professional development (CPD) through reskilling and upskilling training interventions commonly employed in industrial settings. The importance of CPD training interventions is particularly apparent in the current industrial climate, where challenges such as responding to future skills needs, keeping abreast of industry 4.0 related industrial developments and the reskilling of personnel whose roles may have been replaced by automated solutions are ever present.

This research study was funded by Skillnet Ireland and commissioned by First Polymer Training Skillnet (FPT Skillnet). FPT Skillnet is a business network dedicated to supporting companies in the polymer processing sector through the design, development and provision of innovative training programmes. A key aspect of FPT Skillnet's industrial training agenda is to provide information regarding successful approaches to learning and talent development coupled with advice on gauging the effectiveness of training. With these goals in mind, that it is beneficial to consider areas of learning and cognitive development such as spatial skills development, with the overall goal of increasing the effectiveness and impact of training interventions for industrial practices for the future. Historically some trainees have struggled with the more difficult technical concepts as they progress onto advanced training modules and may not engage effectively with all the engineering aspects of these programmes. This also has been found to have an impact on retention levels within programmes of longer duration.

Shortages of skilled polymer technicians and engineers have prompted many employers to develop their existing staff into these higher-level technical roles. This internal development of talent has also highlighted the fact that some, while very experienced lack some of the critical cognitive skills needed for this more advanced technical role. Recent evidence has found spatial ability is an essential mental ability, above mathematics and verbal abilities, for advanced level engineers (Berkowitz & Stern, 2018). This research study hypothesises that participants engaging with First Polymer Training programmes require spatial ability and could significantly benefit and boost their performance by having increased levels of this ability. The resultant study was designed and conducted by a team of engineering education researchers from the Technology Education Research Group (TERG, www.terg.ie) at Athlone Institute of Technology (AIT) which has subsequently become the Technological University of the Shannon, Midlands Midwest as of 1st October 2021. The research was conducted in partnership with management and training staff at FPT Skillnet with the following primary objectives:

- Facilitate a spatial skills training course for industrial technical personnel and evaluate their pre-performance and post-performance scores.
- Analyse the engineering knowledge of industrial personnel undertaking a purpose designed, online injection moulding theory module at FPT Skillnet, before and after their training.
- Employ quantitative analysis methods to investigate if correlations are evident between the participants' spatial skills performance, before and after training.
- Conduct further analyses to investigate if there are existing correlations between participants' spatial skills and their previous educational attainment levels, their industrial experience and ultimately, their engineering knowledge development.
- Interview a random sample of the participants to gather their perceptions in relation to the complexity, feasibility, value and relevance of the spatial skills training intervention.
- Offer final recommendations as to whether specific cognitive development interventions such as spatial skills training could benefit industrial training methods.

The study found that there were no significant findings in relation to the completion of the spatial skills intervention when considered in light of spatial skills test scores before and after training. There were also no significant findings in relation to the participants' spatial skills and their previous education attainment, their industrial experience or their performance in the FPT Skillnet training module. The completion of the online advanced injection moulding theory module that was delivered by FPT Skillnet was found to be of significant benefit to the participants in relation to the development of specific engineering knowledge. The qualitative analysis of the participants' feedback through the conducted interviews highlighted areas of interest in relation to the relevance and benefit of the spatial skills training and led to the final recommendations of the study and areas worthy of further investigation. These final recommendations and proposed future work are outlined in the conclusion chapter where it is proposed that spatial skills training beneficial when undertaken as an early-stage undergraduate engineering student. From the participants' interview responses, it was deemed that they found the training to be pitched at a low level, but did comment on particular elements being challenging and of more use to developing their spatial thinking skills. Participants also commented on how the training had utility in preparing them to undertake the subsequent training module. It is recommended that future work should be carried out to review and adapt the spatial skills training intervention for adult learner industrial personnel, where it would be required to ensure that it is suitable in its complexity, and is tailored to ensure that the participants feel that it is of more relevance to the industrial working environment that they are operating within. Such a tailored spatial skills training programme should then be analysed to investigate if it could significantly improve industrial participants' spatial skills and in turn benefit the efficacy of industrial training interventions. It is also highlighted how industry-based training and education programmes that are aiming to attract school leavers should consider the benefits of spatial skills training for early-stage engineering education students and aim to integrate such training into these programmes of learning.

chapter ONE

Introduction

Introduction

The Irish manufacturing sector comprises approximately 4,000 enterprises, employing over 250,000 people and accounts for almost a third of Ireland's economic output as outlined by Martin Shanahan, CEO of IDA Ireland. The sector also provides regional balance to the Irish economy with more than 80% of manufacturing companies based outside of Dublin (Industry and Business Magazine, 2019). This highlights the critical societal and economic role that the sector plays nationally. Like all sectors, manufacturing faces challenging times due to the global COVID 19 pandemic. Companies are likely to be negatively impacted due to supply chain delays, restricted exports, uncertainty and loss of confidence in the global market. However, other manufacturing companies are facing different challenges, whereby their medical device or PPE products for example are in sudden global demand and the challenge is trying to align production capacity to meet consumer demand. These challenges will most likely result in either job losses or personnel having to transfer positions, resulting in further requirements for industrial training, reskilling and upskilling.

Polymer technology companies form the backbone of the Irish manufacturing sector, where almost 7,000 employees are based across 230 businesses with annual exports of €1.62 billion (Ibec, 2018). The high end, high value nature of manufacturing within the polymer industry in recent times requires polymer processing companies to ensure that they maintain an upskilled talent pipeline. Polymer Technology Ireland focus on the promotion of the industry and the development of the required skilled personnel through the FPT Skillnet and the B.Sc. (ordinary degree) in Polymer Processing Technology apprenticeship programme at Technological University of the Shannon, Midlands Midwest.

Furthermore, changing times within the sector, coming about as a result of the fourth industrial revolution (Industry 4.0) also present challenges as well as opportunities for companies to integrate new technologies whilst developing and upskilling their workforces. Training and upskilling demands are present throughout the organisational levels of firms within the sector, whereby management personnel must adapt to develop strategic leadership and management skills to optimise the implementation of advancing technologies and practices through to the development of operational personnel to ensure that technical staff stay abreast of evolving technologies.

A report by the Expert Group on Future Skills Needs (2018) estimates that 21% of occupations are at high risk due to the demands of Industry 4.0, with a further 65% at medium risk. Occupations associated with processing and operations are at risk, especially those associated with manual work, such as packing and filling machine operatives. Much of the disruption, however, will result in changes to job roles and tasks performed by individuals rather than job losses. New automated technologies can mean that certain manual roles are no longer required and these employees can now avail of upskilling in order to fill more value-added roles. Changing industrial practices can also require associated training to ensure that standards are maintained. A number of organisations such as Engineer's Ireland, the Department of Education and Skills, Skillnet Ireland, and SOLAS offer training to industry to meet these demands. The National Skills Strategy 2025 highlights how our youthful population must be given opportunities to develop their potential, outlining objectives that include; educational and training providers to focus on relevant needs of learners, society and the economy; employers to actively participate in skills development for improved productivity and competitiveness; teaching and learning at all stages of education to be enhanced and evaluated; lifelong learning of those in employment to be promoted and increased; focus to be placed upon active inclusion to support participation in education and training; all aiming to support an increase in the supply of necessary skills to the Irish labour market.

In 2019 Skillnet Ireland delivered workforce development and upskilling through 70 learning networks to 70,270 people, in 18,422 companies across Ireland. Skillnet Ireland's Statement of Strategy 2021-2025 informed by COVID-19 highlights how the agency is reacting and adapting their strategies for future investment and prioritisation of workforce development, reskilling and training for new jobs in uncertain times. It is with this strategic focus in mind that this research study looks to investigate if strategies that have been proven effective for undergraduate engineering education students, could also be beneficial for personnel undertaking industrial training. The study specifically looks to interrogate spatial skills training for the development of a foundational skillset as a means of increasing effectiveness and success rates for industrial training. The study's main aim and associated research questions are outlined below.

1.1. Research Aim

This research aims to investigate the feasibility and benefits of developing spatial skills of participants undertaking formal industrial training. Spatial skills training has been analysed in numerous research studies to discern its effectiveness in supporting undergraduate students to optimise their potential and improve retention rates in their engineering education studies. Industrial training, by its nature is a form of adult education, and this research project aims to explore if training is beneficial for adult learner industrial personnel undertaking training programmes. The overarching aim of the research project is therefore to aid training providers in better understanding learner's cognitive needs and enable them to adapt and revise their programmes accordingly.

1.2. Research Questions

The project had two central research questions:

1. Do practicing engineers enrolled in the online advanced injection moulding theory module offered by FPT Skillnet perform better as a result of their engagement with an online spatial skills intervention?
2. How did the participating engineers perceive their experience of the online spatial training intervention?

In addition to these, a third mixed methods central research question was developed which asked:

3. Could the participant experiences with the online spatial training intervention help explain the findings associated with subsequent performance in the FPT Skillnet training module?

To address these research questions, the following project objectives were identified:

1.3. Project Objectives

1. Measure the performance of industrial personnel undertaking a spatial skills training course, before and after its completion.
2. Measure the performance of industrial personnel undertaking an advanced injection moulding theory module, before and after its completion.
3. Interview participants to evaluate their experiences and perceptions of the spatial skills training intervention.
4. Employ mixed method analyses methods to investigate if the spatial skills training was beneficial for completion of the industrial training module.


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chapter TWO

Theoretical Background

To give context to the current study, a theoretical background will be provided in this section. Specifically, a working definition for spatial ability will be provided which will lead into a presentation of empirical evidence associating spatial ability with engineering. Finally, as the participants included people with industry experience who are therefore regarded as having a high level of expertise, background information will be provided on the circumvention-of-limits hypothesis to describe the theorised relationship between the participants and spatial ability.

2.1 A working definition for spatial ability

A working definition is necessary for **spatial ability** as to date there are multiple ways in which it has been framed or conceptualised (Buckley et al., 2018; McNeal & Petcovic, 2020). Before elaborating on these, it is worth introducing some of the relevant terminology that exists within the literature. Verbally, one of the most often cited definitions of spatial ability is that it is "the ability to generate, retain, and manipulate abstract visual images" (Lohman, 1979, p. 126). Other definitions outline that spatial ability is "the performance on tasks that require: (a) the mental rotation of objects; (b) the ability to understand how objects appear in different positions; and (c) the ability to conceptualise how objects relate to each other in space" (Sutton & Allen, 2011, p. 5) or that it is the "innate ability to visualise that a person has before any formal training has occurred" (S. Sorby, 1999, p. 21). Lohman's definition as well as the definition offered by Sutton and Allen make it apparent that there are different mental operations associated with spatial ability. These different operations relate to what are referred to as **spatial factors**. In other words, spatial factors describe discrete mental operations associated with the generation, retention and manipulation of visual images while spatial ability describes the collective of these spatial factors.

Reflecting on the origin of spatial ability as a construct is useful to give context to contemporary frameworks and models. The first person to examine cognitive abilities relating to what is now known as spatial ability was Sir Francis Galton in the late 1800's. In referring to the 'visualising faculty' Galton's (1880, p. 322) observations provide the first record that spatial ability describes more than one mental operation:

The forms of the visualising faculty which we ought to aim at producing appear to me to be as follows:

> **The capacity of calling up at will a clear, steady, and complete mental image of any object that we have recently examined and studied. We should be able to visualise that object freely from any aspect; we should be able to project any of its images on paper and draw its outline there; we should further be able to embrace all sides of the object simultaneously in a single perception, or at least to sweep all sides of it successively with so rapid a mental glance as to arrive at practically the same result. We ought to be able to construct images from description or otherwise, and to alter them in whatever way we please. We ought to acquire the power of combining separate, but more or less similar, images into a single generic one. Lastly, we should learn to carry away pictures at a glance of a more complicated scene than we can success at the moment in analysing.**

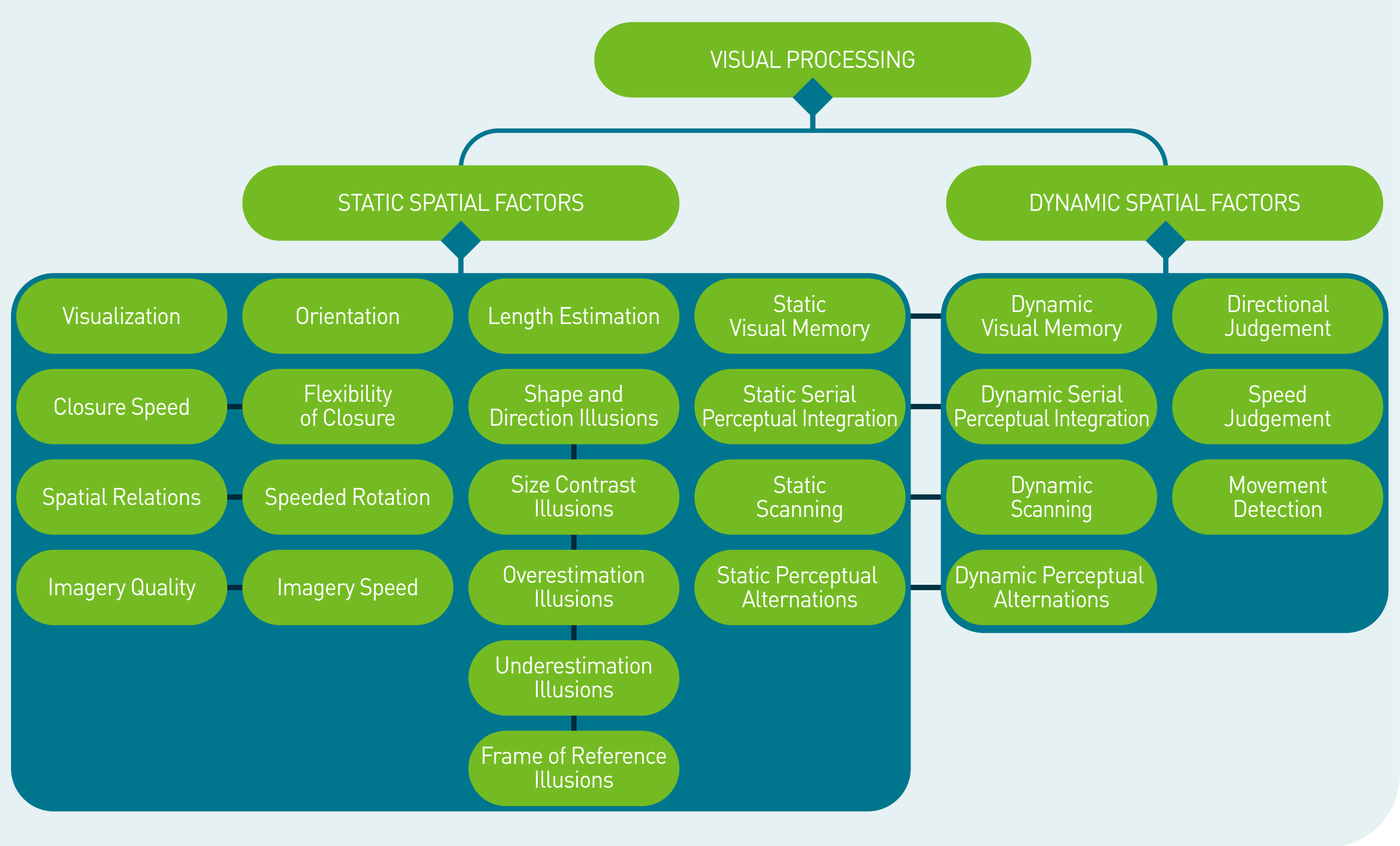
Since Galton's pioneering work, efforts have been invested in (1) empirically investigating if a cognitive ability associated with visual thinking, i.e. spatial ability, existed, independent of general intelligence, (2) once this was determined, in identifying and examining the extent to which the different spatial factors differed from each other, and (3) exploring how different spatial factors related to other cognitive abilities beyond spatial ability (Eliot & Smith, 1983).

The outcomes of this line of work are empirically supported frameworks of spatial ability that represent either different structures of spatial factors or conceptual grouping of relevant mental operations. For example, Newcombe and Shipley (2014) put forward a typology for spatial ability which includes four categories:

- **Intrinsic-static** spatial skills which involve mentally coding spatial features associated with objects such as their size.
- **Intrinsic-dynamic** spatial skills which involve mentally transforming spatial features of objects, such as imagining an object being folded or rotated.
- **Extrinsic-static** spatial skills which involve mentally coding spatial relations between objects such as the distance between them.
- **Extrinsic-dynamic** spatial skills which involve mentally transforming spatial relations between objects as one or more of them or the viewer moves.

Buckley, Seery and Canty (2018) put forward an alternative framework to Galton's model. Where Newcombe and Shipley (2014) differentiate a static-dynamic dichotomy based on whether the object being visualised is mentally still or moving, Buckley et al. (2018) define this dichotomy based on whether the stimulus that a person is going to mentally manipulate is physically still (such as a printed image) or moving (such as on a video). In their framework, Buckley *et al* make the distinction between static and dynamic spatial ability and then, based largely on the Cattell-Horn-Carroll (CHC) theory (Schneider & McGrew, 2018) provide a structure of 25 unique spatial factors which have either been empirically investigated or which were theoretically derived based on other confirmed factors (Figure 1).

FIGURE 1 ▸ HEURISTIC FRAMEWORK OF SPATIAL ABILITY PUT FORWARD BY BUCKLEY ET AL. (2018).



There is a significant limitation in the use of verbal definitions of spatial ability. Comparing the frameworks of Newcombe and Shipley (2014) and Buckley et al. (2018) with the verbal definitions at the beginning of this section shows clearly that they were not sufficiently comprehensive. Therefore, the most appropriate way to define spatial ability is based on an empirical framework. For the purposes of this study, the framework put forward by Buckley et al. (2018) which is presented in Figure 1 will act as that definition.

Working within this framework, there are two final points which need to be clarified: how the included spatial factors are defined, and which factors are of relevance for this study. A similar issue exists in the use of verbal definitions for spatial factors as it does for spatial ability in that there is a lack of consensus on adequate verbal definitions. As these definitions represent discrete mental operations they are not complex enough to require an empirical framework to act as a definition. Instead, they are best defined relative to the measurement instruments within studies to provide an indicator of them. Buckley et al. (2018), in providing an overview of the spatial factors in their framework also note how the evidence linking science, technology, engineering and mathematics (STEM) outcomes with spatial ability most strongly relates to the visualisation factor. This factor is also the most representative of spatial ability as a whole (Carroll, 1997). Therefore, this study focussed exclusively on the visualisation factor which was measured through the Purdue Spatial Visualisation Test: Visualisation of Rotations (PSVT:R: Bodner & Guay, 1997a; Guay, 1977a). A more detailed description of the PSVT:R is provided in section 3.3. Instruments.

2.2. Spatial ability and engineering

There is much evidence linking higher levels of spatial ability to desirable engineering outcomes such as increased disciplinary interest, educational performance and retention. This evidence comes both from large-scale longitudinal studies and small studies within specific areas of engineering. Anecdotal evidence from notable figures provides some of the earliest indication of a link between visualisation and engineering activity (Snow, 1999). For example, Albert Einstein claimed

that thought experiments on visualised systems of waves and physical bodies in states of relative motion aided in achieving insight, and other physicists (e.g. Michael Faraday, James Clerk Maxwell, and Herman Von Helmholtz), generalists (e.g. Francis Galton, Benjamin Franklin, John Herschel, and James Watson) and inventors (e.g. Nikola Tesla and James Watt) displayed high levels of spatial ability and reported that this played an important role in their most creative accomplishments (Lohman, 1993). The strongest evidence that exists for the link between spatial ability and engineering comes from Project TALENT in the U.S. (Wise et al., 1979). Project TALENT involved approximately 400,000 high school students (grades 9 to 12, approx. 100,000 per grade) being tested in 1960 in a variety of areas including mathematical competency, clerical and perceptual aptitude, complex intellectual aptitude, and language ability and aptitude. Since then, there have been a variety of follow up studies with samples of the cohort. One such study was conducted by Wai, Lubinski and Benbow (2009) wherein, using 11-year follow up data from Project TALENT, they examined the participants spatial, mathematical and verbal abilities as predictors for entering and earning higher degrees in different disciplines. In arguably one of the most important findings in educational psychology, Wai et al. (2009) found that participants who went on to earn degrees (Bachelors, Masters and PhD's) in engineering had on average a higher level of general ability (defined as verbal, spatial and mathematical ability) at the time of initial testing in high school than those who went on to earn degrees in other fields (education, business, arts, social science, humanities, biological science, mathematics/computer science, and physical science). It was also found that on average, participants who earned a Masters degree in engineering had higher verbal, spatial, and mathematical abilities in high school than those who went on to earn a Bachelors degree in engineering, and likewise that participants who went one to earn a PhD in engineering displayed higher abilities in these areas than those who went on to earn a Masters degree in engineering. Of particular relevance for this study was that spatial ability was found to be a predictor of engineering success (defined by achievement of a higher degree) beyond mathematics and verbal ability. More generally in STEM areas, Wai et al. (2009) concluded that "the importance of spatial ability increases as a function of successively more advanced educational credentials" (p. 825).

While the longitudinal data presented by Wai et al. (2009) is perhaps the most important data with respect to the predictive capacity of spatial ability for engineering, there is also much data linking spatial ability with specific engineering educational fields (Deno, 1995; Hsi et al., 1997; Miller, 2015; Pleck, 1991), and documenting its malleability (S. Sorby et al., 2018; Stieff & Uttal, 2015; Uttal et al., 2013). For example, Sorby et al. (2014) found statistically significant correlations between Irish engineering students and subsequent performance in modules in CAD/engineering graphics, physics and computer programming. Further, Buckley et al. (2019) found evidence suggesting that spatial ability relates to university students' capacity to solve geometric problems similar to those found in engineering graphics courses and in a review article, Mix and Cheng (2012, p. 206) note that "the relation between spatial ability and mathematics is so well established that it no longer makes sense to ask whether they are related".

With the existing evidence highlighting a relationship between engineering and spatial ability, research progressed to explorations into how this could be capitalised upon to improve engineering education. Much of this work has been pioneered by Prof. Sheryl Sorby over the last three decades. In 1993, Sorby and colleagues received funding to develop a course for freshman engineering students in the U.S. who had weak visualisation skills (S. Sorby & Baartmans, 1996). Since then, this course has been the subject of much research particularly with university level engineering students, with a recent large scale longitudinal study (S. Sorby et al., 2018) concluding that it does improve STEM outcomes at university level. This research, in conjunction with meta-analytic findings that spatial ability is malleable and can be positively affected by targeted interventions leading to improved STEM outcomes (Stieff & Uttal, 2015; Uttal et al., 2013) exemplifies a mechanism for supporting engineering education. However, it should be noted that to date, the vast majority of this research has been conducted in higher education settings and there is little evidence exploring the role of spatial ability with industry level engineering personnel who have more experience and disciplinary knowledge. Thus, it is necessary to consider the role that disciplinary expertise can have on the potential impact of spatial ability on improved educational outcomes for more experienced learners. With respect to this, the circumvention-of-limits hypothesis has much to offer.

2.3. The circumvention-of-limits hypothesis

A significant finding from Sorby et al. (2018) was that the impact of the spatial training course on engineering course performance decreased as students' math ACT scores increased. In other words, the spatial training course was less useful in terms of engineering performance for students with higher levels of mathematics knowledge than those with lower levels of mathematics knowledge. This aligns with the circumvention-of-limits hypothesis (Salthouse, 1991) which posits that "the effect of domain general abilities and capacities on performance diminishes as skill in a task is acquired through training" (Hambrick et al., 2018, p. 307). Beyond the study conducted by Sorby et al. (2018) which relates directly to spatial ability and engineering, there is further supporting evidence for the circumvention-of-limits hypothesis in the areas of physics (Kozhevnikov & Thornton, 2006), geospatial mapping (Hambrick et al., 2012), and chemistry (Stieff, 2007). In any study, such as the one described in this report, where a relationship is being explored between a general cognitive ability such as spatial ability and disciplinary performance of experts, it must be acknowledged that participants with a certain level of expertise may not require the use of the general cognitive ability. Given that much of the evidence associating spatial ability comes from higher level engineering education, similar results may not be found in an industry level context.

chapter THREE

Methodology

3.1. Approach

As previously presented, this project had two central research questions:

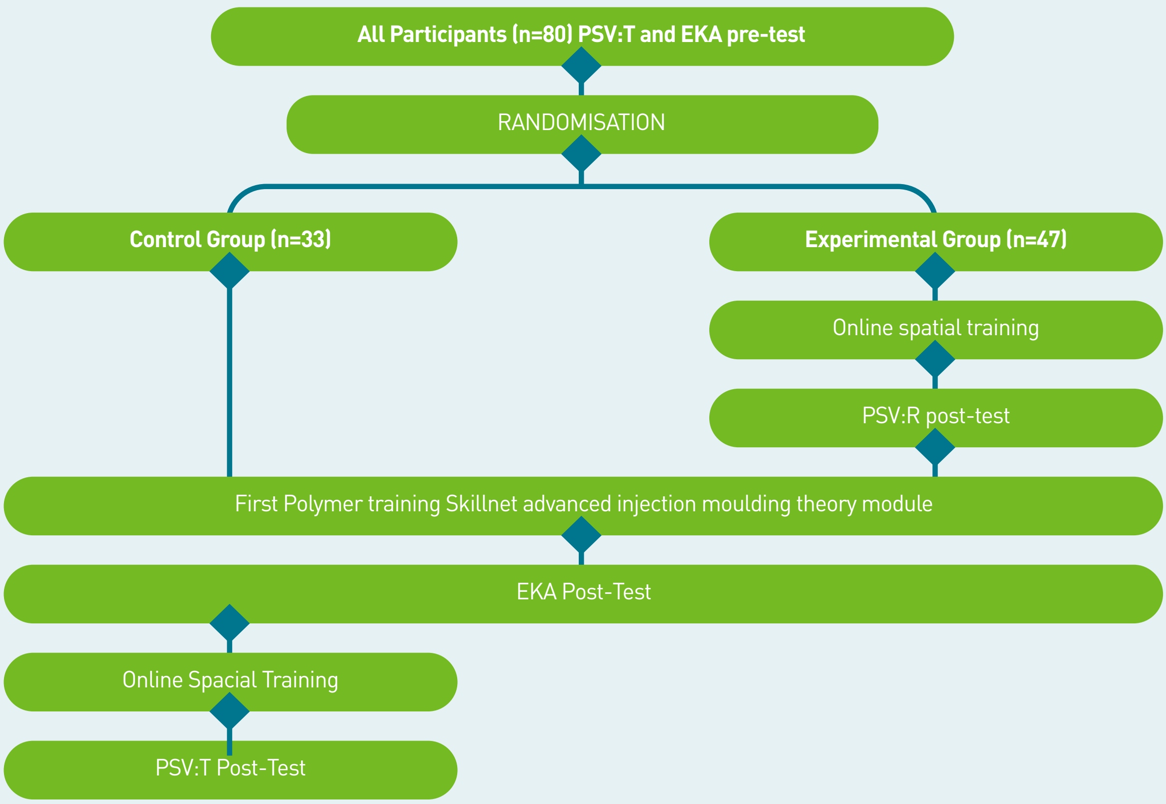
1. Do practicing engineers enrolled in the online advanced injection moulding theory module offered by the FPT Skillnet perform better as a result of their engagement with an online spatial skills intervention?
2. How did the participating engineers perceive their experience of the online spatial training intervention?

In addition to these, a third mixed methods central research question was developed which asked:

3. Could the participant experiences with the online spatial training intervention help explain the findings associated with subsequent performance in the FPT Skillnet training module?

To address these questions, an explanatory sequential mixed methods design was employed in this study. Specifically, a quantitative experimental design was developed in response to the first research question with follow up qualitative interviews. The quantitative randomised control trial was conducted wherein participating engineers were randomly assigned to either an experimental or control group. All participants were initially administered the PSVT:R as a measure of spatial ability and an engineering knowledge assessment (EKA) developed by FPT Skillnet. Following this, those in the experimental group completed the online spatial training intervention and a PSVT:R post-test prior to engaging with the FPT Skillnet advanced injection moulding theory module and EKA post-test. In contrast, following the pre-tests, the control group engaged with the FPT Skillnet training module and EKA post-test and then completed the online spatial training intervention and PSVT:R post-test. This permitted comparison between both groups after they had completed the FPT Skillnet training module where only the experimental group had completed the spatial training intervention, with the intervention still being offered to the control group for ethical purposes. The experimental design can be seen in full in Figure 2.

FIGURE 2 ▸ EXPERIMENTAL DESIGN



Following this, participants from the experimental group were invited to volunteer to be interviewed about their experiences. The interviews were semi-structured, with questions asked relating to four thematic areas including:

- Perceived difficulty of the spatial skills intervention,
- Perceived feasibility of the intervention,
- Levels of enjoyment and engagement regarding the intervention, and
- Any perceived benefit or relevance of the intervention.

3.2. Participants

Companies from several industry sectors involving polymer engineering including medical device production, automation, food, energy, transport, and construction were invited by FPT Skillnet to engage with this study. Interested companies received an on-site presentation by members of the research team on the benefits of spatial ability for engineering, where results of empirical studies which were predominantly contextualised in tertiary level engineering education were presented. This presentation also included an explanation of the nature of the study, and informed employees that as compensation for participation, there would be no financial cost associated with either the spatial training intervention or the FPT Skillnet advanced injection moulding theory module. In the event that a company was interested in the study but an on-site presentation was unable to be scheduled, an online webinar was arranged whereby the same presentation was provided. For companies that could not attend the online webinar, a recording of the webinar session was provided. Following this, a total of 42 companies expressed interest with 136 employees volunteering into the study who were randomly divided between experimental and control conditions.

Due to the COVID-19 pandemic, and the impending additional pressures and disruption to industrial activities, resulting in redundancies and large number of employees transitioning to working from home, there was a high level of attrition during the study. Of the initial 136 participants, a total of 80 (M_{age} = 40.83, SD_{age} = 8.78) completed the experimental phase study of which 77 were male and 3 were female. Of these, 47 participants were in the experimental group and 33 were in the control group. These 80 participants came from 31 different companies. Table 1 presents a breakdown of demographic information for the 80 participants including self-reported highest level of formal qualification relative to the Irish National Framework of Qualifications (NFQ) and aggregated data on self-reported years of industrial experience.

TABLE 1 SAMPLE DEMOGRAPHIC STATISTICS

Highest Formal Qualification Level (NFQ)	% of Cohort	*n*	Age	Industrial Experience (Years)						
				1-5	6-10	11-15	16-20	21-25	26-30	30+
No Formal Qualifications	1.25	1 (1 male)	35	1	-	-	-	-	-	-
Level 5	12.5	10 (9 male 1 female)	M = 40.5 SD = 9.07	2	3	-	4	-	1	-
Level 6	16.25	13 (13 male)	M = 41.42 SD = 8.07	4	3	2	2	1	1	
Level 7	21.25	17 (17 male)	M = 42.71 SD = 5.88	3	2	5	3	2	2	
Level 8	15	12 (11 male 1 female)	M = 40 SD = 13.06	6	2	1	-	1	-	2
Level 9	6.25	5 (4 male 1 female)	M = 34 SD = 8	3	1	1	-	-	-	-
No demographic information provided	27.5	22 (22 male)		-	-	-	-	-	-	-

Immediately following the experimental group's completion of the EKA post-test, which signified an end to their engagement with the experiment, 20 participants selected at random were invited to be interviewed on their experience. Ten participants volunteered to be interviewed. Using pseudonyms to preserve anonymity, Table 2 presents demographic information for each of the interviewees

TABLE 2 DETAILS OF VOLUNTEERING INTERVIEWEES

Pseudonym	Gender	SS Pre-Test Score	Highest Formal Qualification Level (NFQ)	Role/Job Title	Industrial Experience (Years)
Alan	Male	20	Level 8	Moulding Engineer	3
Brian	Male	14	Level 6	Process Technician	17
Chloe	Female	11	Level 8	Technical Writer	4
Derek	Male	16	Level 8	Project Engineer	6
Erik	Male	23	No Formal Qualifications	Process Technician	1
Giedrius	Male	25	Level 6	Process Technician	4
Hermina	Female	30	Level 9	Senior Moulding Engineer	3
Ivan	Male	24	Level 9	Polymer Engineer	8
John	Male	27	Level 7	Process Technician	8
Kevin	Male	16	Level 7	Trainer	17

3.3. Instruments

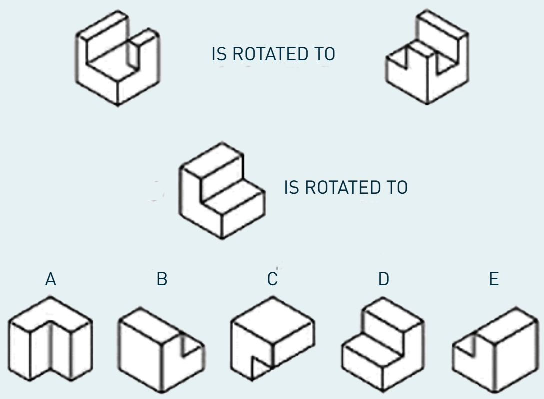
3.3.1. The Purdue Spatial Visualization Test: Visualization of Rotations

The PSVT:R (Bodner & Guay, 1997b; Guay, 1977b) is a validated psychometric test of spatial ability which can be administered in a paper and pencil format or online. In this study, it was administered via an online platform. Participants are given 20 minutes to complete the test which contains 30 multiple choice questions. Figure 3 presents a sample item, not one which is part of the test, as well as partial directions. The test items follow the exact same format as is presented in Figure 3, progressing in difficulty by including more required mental rotations. In the online administration of the PSVT:R in this study, participants had unlimited time to study the directions before choosing when to begin the test, at which point the timer began. Participants completed the test unsupervised.

FIGURE 3 ▸ PSVT:R DIRECTIONS AND SAMPLE ITEM

DIRECTIONS

This test consists of 30 questions designed to see how well you can visualise the rotation of three-dimensional objects. Shown below is an example of the type of question included in this test.



You are to:
1. Study how the object in the top line of the question is rotated
2. Picture in your mind what the object shown in the middle line of the question looks like when rotated in the same manner
3. Select from among the five drawings (A, B, C, D or E) given in the bottom line of the question the one that looks like the object rotated in the correct position

What is the correct answer to the example shown above?

Answer A, B, C and E are wrong. Only drawing D looks like the object rotated according to the given rotation. In this test each question has only one correct answer.

3.3.2. First Polymer Engineering Knowledge Assessment

The EKA was developed by FPT Skillnet as a measure of polymer engineering knowledge. The test contained 100 multiple choice questions, all of which had 1 correct answer but 5 possible response options. These were presented both via PowerPoint and orally by the instructor. Questions were scored as either correct (1 point) or incorrect (0 points) meaning the maximum score achievable was 100. Participants were afforded 60 minutes to complete the test, which was administered by FPT Skillnet. All questions related to the material within the advanced injection moulding training module described in section 3.3.3. An example of a question is;

"The injection rheology curve shows us:"

a) How stiff the melt is.

b) How runny the melt is.

c) How fast we have to inject to fill the mould.

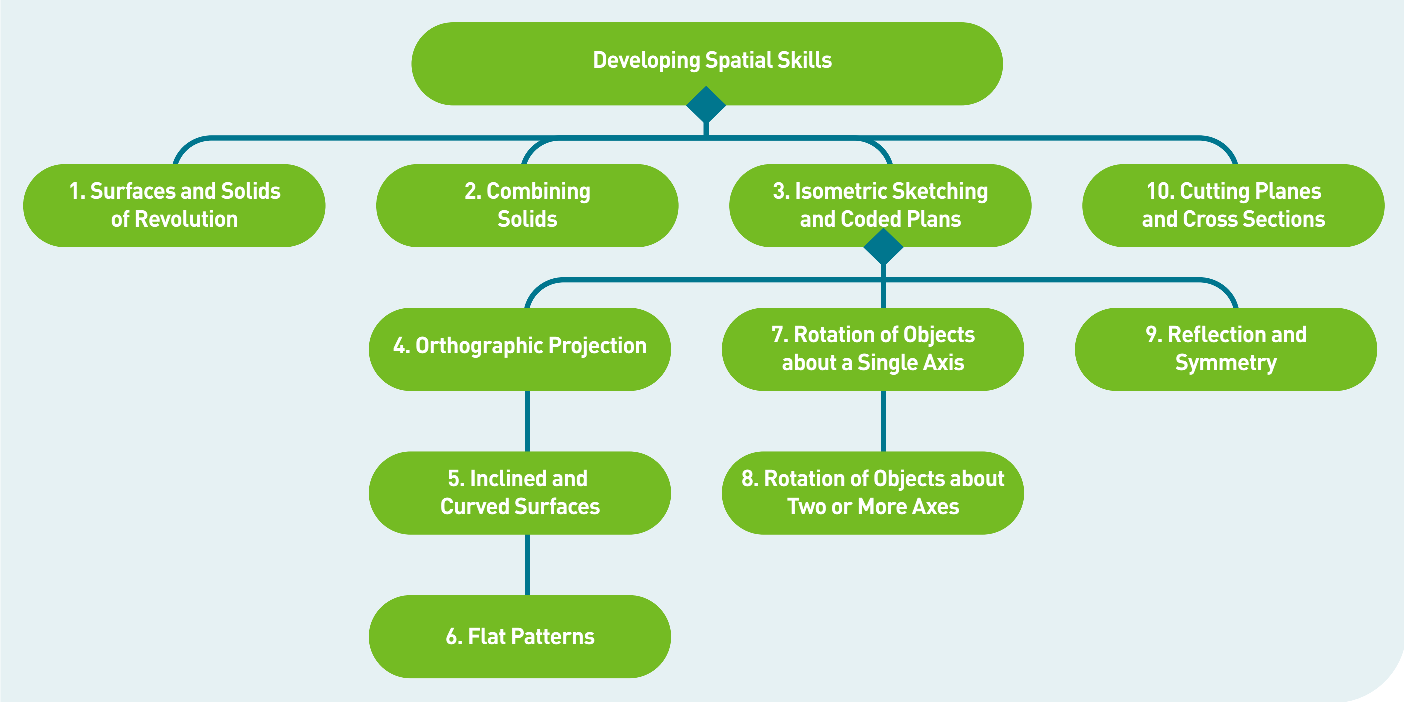
d) How fast we have to inject before the melt viscosity stops changing - to reduce batch to batch variation.

e) The injection time we need to avoid short shots.

3.3.3. Developing Spatial Thinking Intervention

The spatial training intervention, "Developing Spatial Thinking" (S. Sorby, 2009) contains a curriculum of 10 modules that has been proven to improve the spatial skills of undergraduate engineering students (S. Sorby et al., 2018). Each module contains web-based tutorial videos and online exercises, as well as an accompanying workbook for participants to complete. The modules are designed to take approximately 90 minutes each and prior work has implemented the intervention over a ten-week period with participants completing one module per week. Figure 4 presents a schematic which identifies the topics of each of the ten modules.

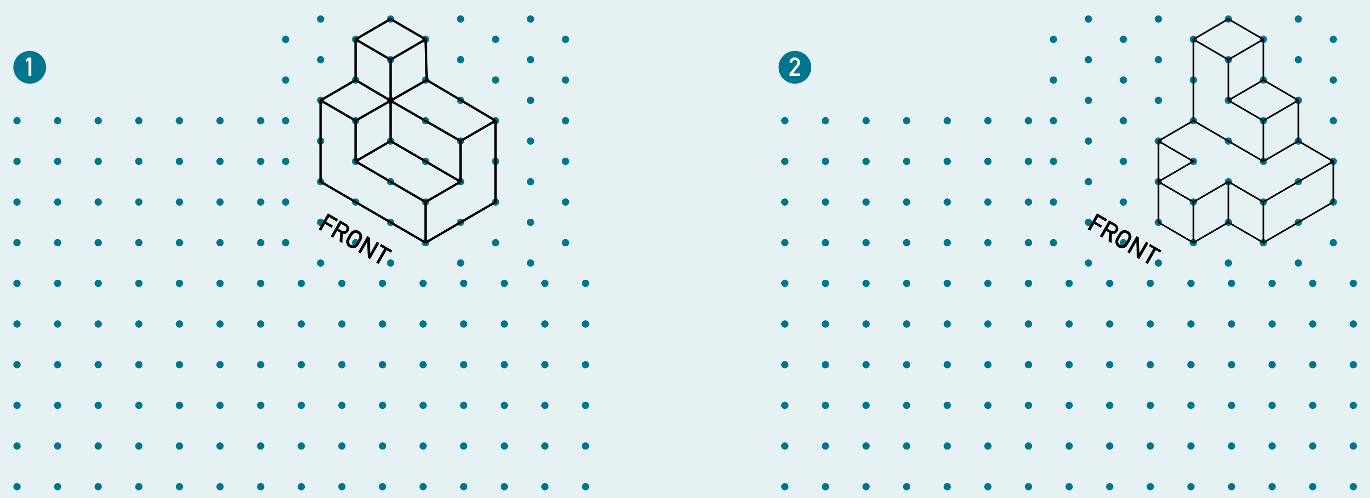
FIGURE 4 ▸ DEVELOPING SPATIAL THINKING INTERVENTION MODULES



In this study, the intervention was delivered via an online platform (S. Sorby, 2020) and rather than the typical 10-week timeframe, participants engaged with the intervention in a self-paced manner over a 3-week period using the online resources at their own discretion. The decision to deviate from the traditional offering of the module was made to reflect a logistically feasible approach for industry personnel, which should the result indicate a benefit, could be manageable after this study. As evidence of completing a module, participants uploaded a scanned copy of the completed section in their workbook to the online platform. An example of the type of activity within their workbook is shown in Figure 5. Specifically, in this example participants were asked to sketch orthographic views of a provided geometry, depicted in an isometric view.

FIGURE 5 ▸ WORKBOOK EXAMPLE

For the objects shown in isometric below, sketch the top, front, and right side views in the space provided.
Make sure your views are properly aligned.



3.3.4. Advanced Injection Moulding Theory Module

The online advanced injection moulding theory module, delivered by FPT Skillnet, is an adapted theoretical version of their standard Injection Moulding 3 module, which is the third in a series of four injection moulding training modules that FPT Skillnet deliver in their dedicated training facility. This stream of modules is typically delivered with a strong practical emphasis, whereby the theory of the modules is contextualised through practical work on injection moulding training machines. The adapted version employed for this study was a purely theoretical lecture-based module, tailored to be offered online so that employees could undertake the training in their place of work or at home. The theoretical level of the content is considered to be advanced as there is significant prerequisite knowledge and experience required to undertake the module. The module was designed specifically for technical practitioners such as machine setters and moulding engineers who are responsible for process setup and optimisation within polymer processing environments. The learning outcomes of this module are that at the end of the course trainees should be able to:

1. List causes of shot to shot variation caused by the injection moulding machine hardware.
2. List causes of shot to shot variation caused by the plastic material.
3. List causes of shot to shot variation caused by the injection moulding process parameters.
4. Describe what the terms Cp, CpK, Standard Deviation, Average and Range mean.
5. Write out the equation to calculate the Process Capability Index Cp.

The module was delivered in the form of six pre-recorded lectures. Each lecture was one hour in duration and participants engaged with this in a self-paced manner over the course of three weeks.

3.3.5. Post-Intervention Questionnaire

A semi-structured interview was designed to gather insight into a sample of the participants' perceptions and attitudes towards the spatial skills training intervention. The main objectives of the interview design were to investigate if the participants found particular elements to be too easy or difficult, if the completion of the intervention was achievable during their working week, if they found the content to be enjoyable and to what level they felt they engaged with the intervention, and finally how beneficial or relevant they found the training intervention. The complete interview protocol is located at https://osf.io/9z4nt/.

The interviews were conducted via Zoom in all but one of the cases where, due to technical difficulties, the interview was conducted via telephone. All interviews were conducted by the same member of the research team and audio was recorded for subsequent transcription by that same member.

3.4. Implementation

Ethical approval for this research was awarded by the Athlone Institute of Technology Research Ethics Committee prior to a recruitment phase which ran from November 2019 to February 2020. During this time, companies were contacted with respect to the study and on-site presentations were delivered where possible. As noted above, in the event that the presentation could be not delivered on-site, a live or recorded online presentation was provided to the company. All intentions to participate were received prior to March 2020.

All participants received the EKA pre-test and the PSVT:R pre-test in the first week of March 2020. The EKA pre-test was administered by the FPT Skillnet instructor and the PSVT:R was administered by a member of the research team via a dedicated online platform. Administration of the EKA was conducted under supervised conditions, while the PSVT:R was unsupervised. Following pre-testing, the experimental group were given access to the online spatial training intervention and received a physical workbook. Due to the ongoing pandemic in some instances the workbooks were posted to companies who took responsibility for distribution amongst employees but in other circumstances workbooks were sent via post to participants' home addresses. Participants were given three weeks to engage with the intervention in a self-paced manner and were asked to uploaded scans of workbook sections as they completed them. During this time, they were offered any requested support by a member of the research team. The intervention was completed by all participants in the experimental group by the 6th of April 2020. At the end of the intervention, participants completed a PSVT:R post-test in the same online platform.

All participants from both the control and experiment groups engaged with the online self-paced injection moulding theory module between the 7th and 28th of April 2020. During the week following this module all participants completed the post-test EKA under the same conditions as the pre-test EKA. Finally, participants in the control group were afforded the opportunity to engage with the spatial training intervention during May 2020 under the same conditions as the experimental group. The same workbooks were made available to participants and the same support was provided where necessary.

Following the experiment, invitations to engage with a semi-structured interview were sent to 20 participants from within the experimental group. Of these, 10 people volunteered and liaised with a member of the research team to schedule an appropriate time. The interviews were conducted between May and June 2020 and typically lasted from 20-30 minutes. Due to the COVID-19 pandemic and associated restrictions, interviews were conducted via Zoom except in one instance where the interview was conducted via telephone. One member of the research team, the same person who had offered support during the spatial training intervention, conducted the interviews as there was familiarity between the researcher and participants. All interviews were audio recorded only and participants were made aware of this. The recordings were subsequently transcribed verbatim.

chapter FOUR

Quantitative Results

4.1. Descriptive Statistics

While a total of 136 participants expressed an interest in participating in the study and completed some elements, 56 withdrew participation formally or were discarded from the analysis due to significant levels of missing data. Of the original participants, 80 completed at least 3 of the PSVT:R pre- and post-test and EKA pre- and post-test. Only data from these 80 participants was included in the analysis. Demographic information for these 80 participants is presented in Table 1. Table 3 presents descriptive statistics for these participants outlining their industrial experience, performance in the PSVT:R pre and post-test and the EKA pre and post-test.

The rest of this section is structured around the following questions designed to support the answering of the central research questions:

1. Is there an association between spatial ability and the highest level of formal education attained by the participants?
2. Is there an association between how much experience the participants had in the polymer engineering industry and spatial ability?
3. Did participants' level of spatial ability increase as a result of the spatial ability intervention?
4. Did participants' level of polymer engineering knowledge increase as a result of the First Polymer training module?
5. Did the intervention have an effect on performance on the EKA post-test?

The selection of statistical tests conducted to answer the above questions was informed by whether relevant assumptions were violated or not. Details of tests of statistical assumptions can be found in the Supplementary Materials located at https://osf.io/9z4nt/.

TABLE 3 ▸ DESCRIPTIVE STATISTICS

	Mean	SD	Median	MAD	Min	Max	Skewness	Kurtosis	SE
Males (n = 77)									
Years experience	11.818	8.838	12	10.378	1	30	.525	-.906	1.192
Spatial ability (Pre-test)	19.104	6.187	19	7.413	3	30	-.348	-.571	.705
Spatial ability (Post-test)	20.338	5.212	21	5.930	11	30	-.090	-1.210	.619
Polymer knowledge (Pre-test)	50.273	13.449	47	11.861	18	79	.019	-.313	1.533
Polymer knowledge (Post-test)	65.514	14.275	67.5	12.602	21	89	-.875	.668	1.706
Females (n = 3)									
Years experience	4.333	1.528	4	1.483	3	6	.208	-2.333	.882
Spatial ability (Pre-test)	18.333	10.214	14	4.448	11	30	.348	-2.333	5.897
Spatial ability (Post-test)	20.333	8.505	17	4.448	14	30	.332	-2.333	4.910
Polymer knowledge (Pre-test)	48.333	20.502	37	1.483	36	72	.384	-2.333	11.837
Polymer knowledge (Post-test)	56.333	27.392	51	28.169	32	86	.187	-2.333	15.815

Note: SD = Standard deviation. MAD = Median absolute deviation. SE = Standard error.

4.2. Spatial ability and the Participants' highest level of formal education

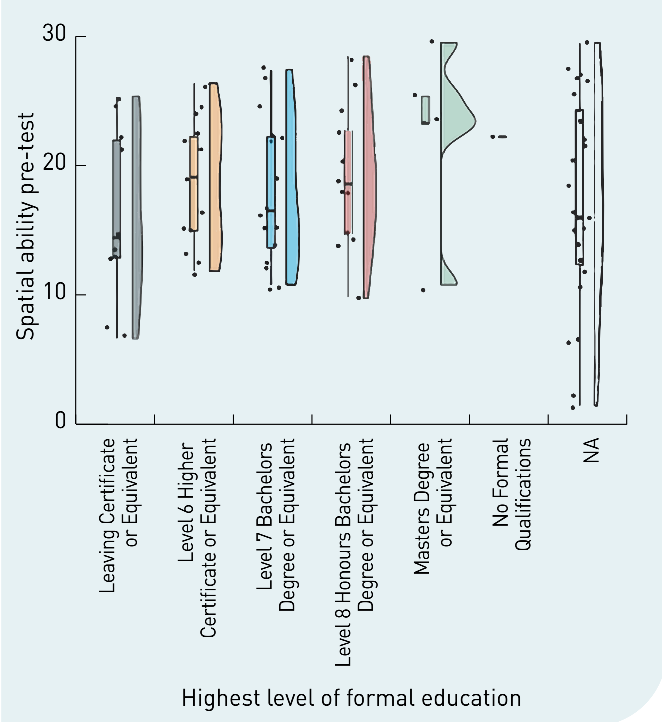
The first question of interest was whether there was an association between having a higher level of formal qualification based on the Irish NFQ scale and having a higher level of spatial ability as measured by the PSVT:R before any intervention. This particular question has relevance when considering the work of Wai et al. (2009) who found that people's level of spatial ability at age 15-18 was a predictor of formal qualification in engineering 11 years later.

Figure 6 presents this data where scores of the PSVT:R pre-test are plotted across participant self-reported formal qualifications.

In Figure 6, one participant reported to having no formal qualification in alignment with the NFQ scale, and many did not disclose their levels of qualification (denoted by NA). A visual examination of participants who did provide this information highlighted how the upper limits of the distribution curves followed a trend linking educational attainment to spatial ability, however much overlap between the categories of educational attainment suggests that holding a higher level of educational qualification does not relate to increased levels of spatial ability.

In analysing this data statistically, based on their relatively small sample size, participants reporting to hold a Masters qualification or no formal qualification

FIGURE 6 ▸ PARTICIPANT PRE-TEST PSVT:R SCORES ACROSS LEVELS OF FORMAL EDUCATIONAL ATTAINMENT



from the NFQ scale were excluded from the analysis, as were those who did not disclose their qualification. A Kruskal-Wallis rank sum test was performed to examine performance differences across each group. No significant difference in spatial ability was found between the four groups, those holding a Level 5 (M=18.60, SD=5.50), Level 6 (M=19.96, SD=5.25), Level 7 (M=19.25, SD=5.23), or Level 8 (M=20.70 SD=4.79) qualification, x^2 (3)=1.442, *p*=.696. Therefore, this study found no empirical evidence for a relationship between level of spatial ability as measured by the PSVT:R and holding a higher formal education degree in this sample.

FIGURE 7A ▸ PARTICIPANT PRE-TEST PSVT:R SCORES ACROSS LEVELS OF FORMAL EDUCATIONAL ATTAINMENT

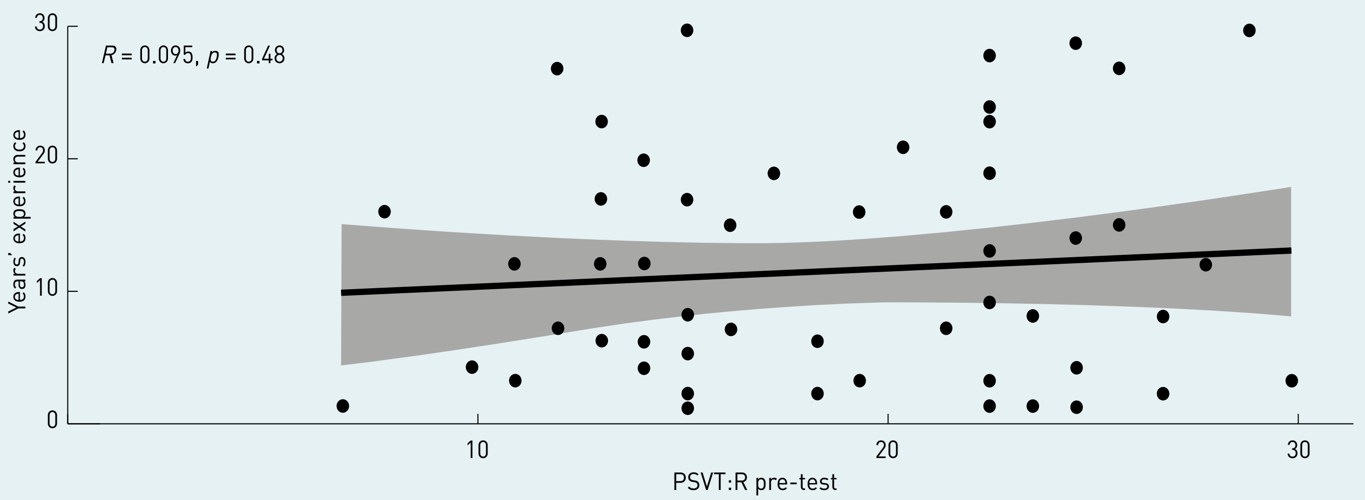
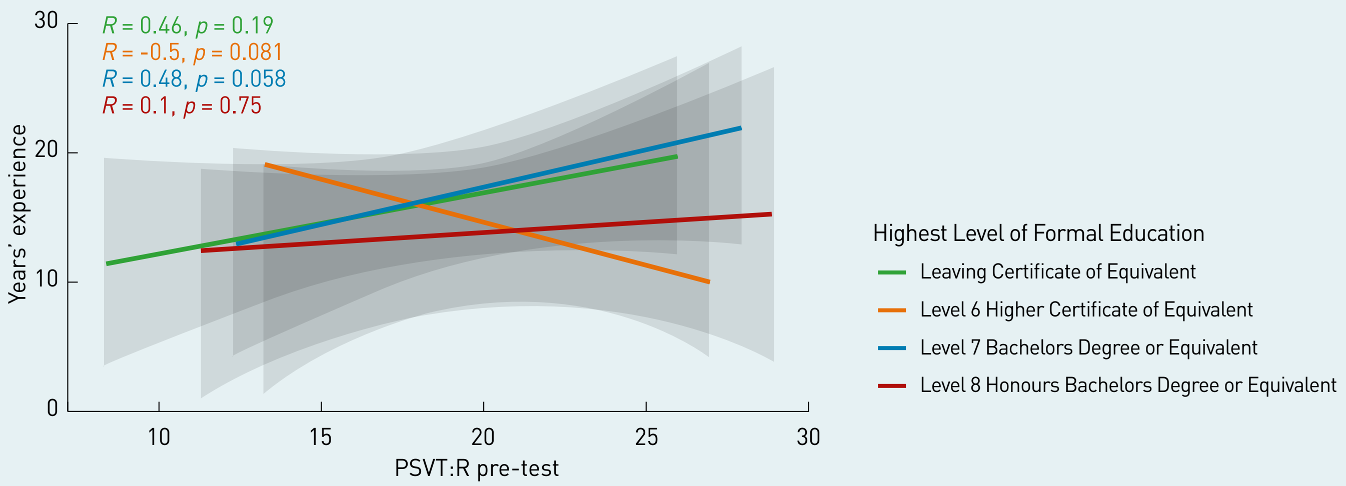


FIGURE 7B ▸ PARTICIPANT PRE-TEST PSVT:R SCORES ACROSS LEVELS OF FORMAL EDUCATIONAL ATTAINMENT



4.3. Spatial ability and the participants' polymer engineering industrial experience

The next area of interest was to question whether there was a correlation between having more industrial experience and having higher levels of spatial ability. Such a correlation could indicate that engaging with engineering industry over time leads to an increased level of spatial ability in adults. To examine this, a Pearson's correlation was examined between performance in the pre-test PSVT:R and the number of years' experience participant had in the polymer engineering industry. A very weak and non-significant correlation was found, r=.095, p=.48, providing no evidence for a relationship between how much time is spent in industry and developed levels of spatial ability (Figure 7A). Following this, a similar correlational analysis was conducted between spatial ability and the number of years' experience participants had however this time the data was examined with respect to the highest formal qualification participants reported to hold. The correlations were found to be stronger (Figure 7B), but once again, no significant correlations were observed. This data presents no evidence that, at least for adults, spending time in the polymer engineering industry could lead to increased spatial skills.

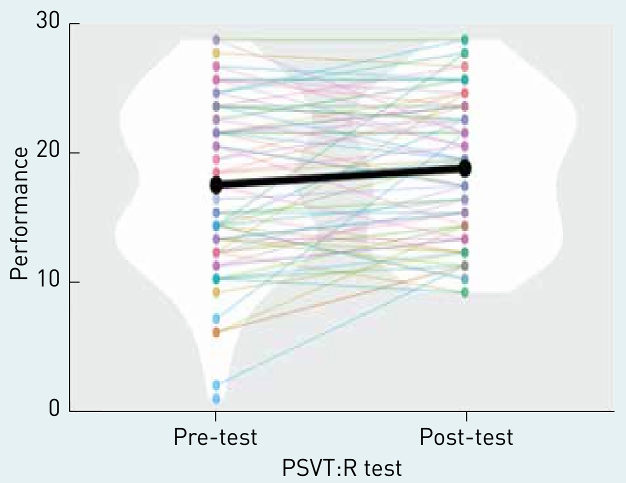
4.4. Impact of spatial ability intervention on participants' spatial ability

With no evidence existing that engaging in industrial activity alone resulted in an increase in spatial ability amongst the participants, it was of interest to determine whether the spatial skills training intervention which has been proven effective for higher education engineering students had an impact on their levels of spatial ability. It should at this point again be noted that this intervention was not engaged with by participants through conventional means as discussed in the methodology. To determine if the intervention impacted participants' levels of spatial ability, pre- and post-test performance in the PSVT:R test was compared. As in the previous analysis, the data was initially examined for all participants, and then for participants with different levels of formal qualification.

First, performance was compared for all participants who completed the pre- and post-test PSVT:R. A Wilcoxon two-sample paired signed rank test was conducted to compare performance differences in pre-test (M = 19.07, SD = 6.28, Med = 19, MAD = 7.41) and post-test (M = 20.34, SD = 5.29, Med = 21, MAD = 5.93) scores. A non-significant result was observed, V = 812.5, p = .061, r = .219 [.02, .44]. Therefore, no evidence was found that the intervention effected participants levels of spatial ability.

Figure 8 illustrates changes in pre- and post-test performance for each participant and it is apparent that there were mixed effects resulting from the intervention. A small increase in mean score was observed and the lower tail in the pre-test, which represented 5 participants, was not apparent in the post-test data.

FIGURE 8 ▸ PSVT:R PRE- AND POST-TEST PERFORMANCE COMPARISON

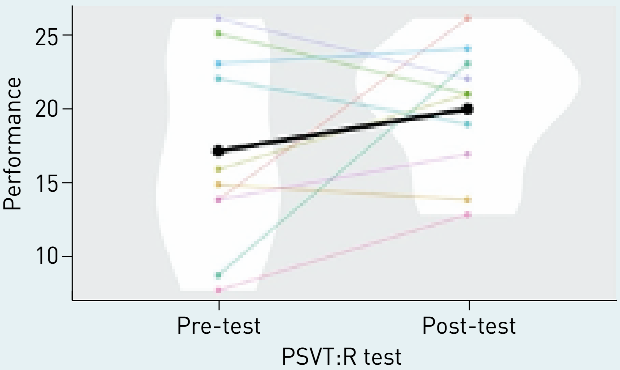


To examine whether the intervention resulted in an improvement in participants' spatial skills for participants with varying levels of formal education, four separated paired t-tests were conducted with participants reporting to hold a Level 5, 6, 7, and 8 qualification respectively (Figure 9). For participants holding a Level 5 qualification, the result of a paired t-test conducted between performance on the PSVT:R pre-test (M = 17.2, SD = 6.44) and post-test (M = 20, SD = 4.24) was not statistically significant, t(9) = 1.39, p = .2, d = .502 [-.302, 1.307]. For participants holding a Level 6 qualification, the result of a paired t-test conducted between performance on the PSVT:R pre-test (M = 19.62, SD = 4.84) and post-test (M = 20.33, SD = 5.85) was not statistically significant, t(11) = .219, p = .83, d = .046 [-.386, .477]. For participants holding a Level 7 qualification, the result of a paired t-test conducted between performance on the PSVT:R pre-test (M = 18.88, SD = 5.34) and post-test (M = 19.62, SD = 5.26) was not statistically significant, t(15) = .725, p = .48, d = .141 [-.259, .542]. Finally, for participants holding a Level 8 qualification, the result of a paired t-test conducted between performance on the

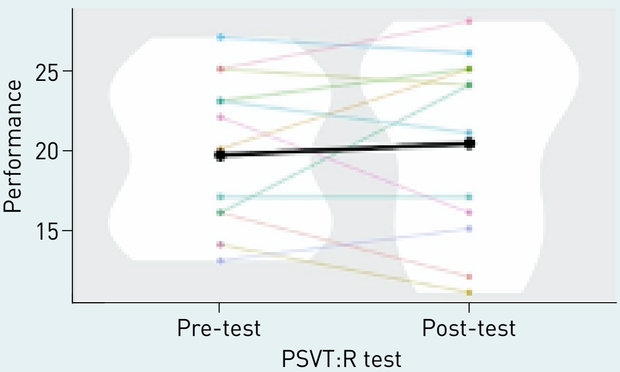
PSVT:R pre-test (M = 20, SD = 5.34) and post-test (M = 21.45, SD = 4.23) was not statistically significant, t(10) = .2.13, p = .059, d = .159 [.002, .315]. The results from each of these analyses together provide no evidence that the intervention, at least delivered under the conditions of this study, had an effect on participants' levels of spatial ability.

FIGURE 9 ▸ PSVT:R PRE- AND POST-TEST PERFORMANCE COMPARISON BY HIGHEST NFQ LEVEL OF ATTAINMENT

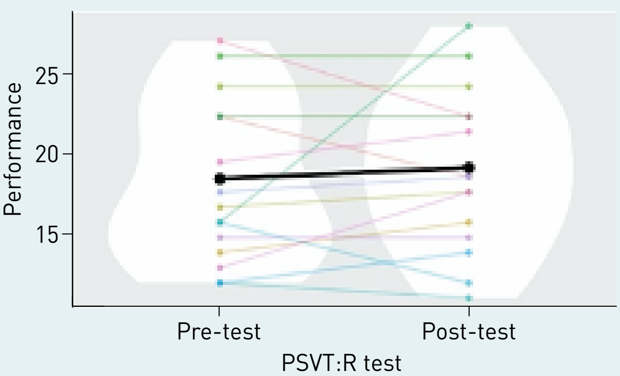
A: NFQ LEVEL 5



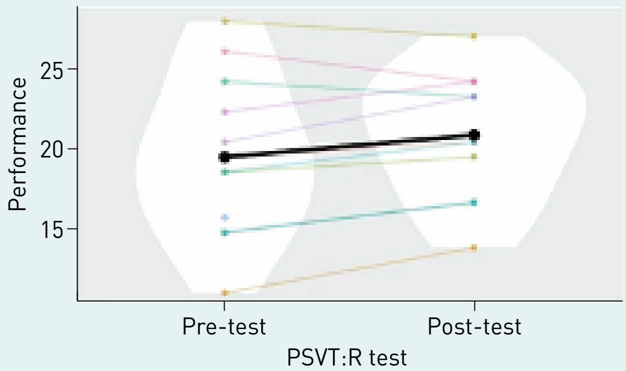
B: NFQ LEVEL 6



C: NFQ LEVEL 7



D: NFQ LEVEL 8



4.5. First Polymer Training Skillnet module efficacy for engineering knowledge development

While there was no evidence found that spatial ability develops as a result of time spent in the polymer industry, or that the training intervention had an effect on participants' levels of spatial ability, the impact of the FPT Skillnet training module on the participants' knowledge of polymer processing as measured by the EKA is still of substantial interest. Having a positive impact come from this module would suggest that professional development of practicing engineers, at least until further evidence associated with spatial ability in adult populations is acquired, would be best orientated around disciplinary knowledge and skills. To answer this question, participants were considered in four groups (Figure 10);

A. All participants,

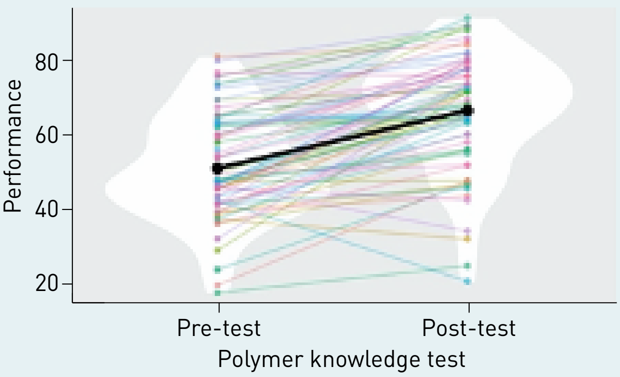
B. Those who had previously completed injection moulding module 1, i.e., those with the lowest prior knowledge acquired via formal means,

C. Those who had previously completed injection moulding modules 1 and 2, and

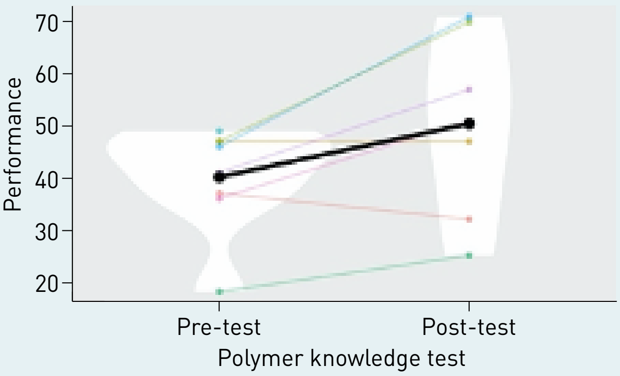
D. Those who had previously completed injection moulding modules 1, 2 and 3, i.e. those with the highest prior knowledge acquired via formal means.

FIGURE 10 ▸ PSVT:R PRE- AND POST-TEST PERFORMANCE COMPARISON BY PRIOR FPT SKILLNET MODULE COMPLETION

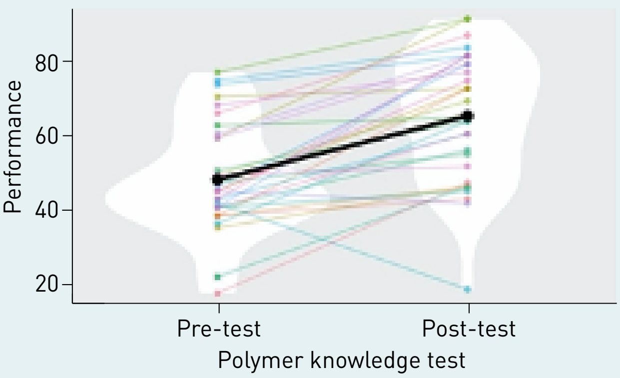
A: ALL PARTICIPANTS



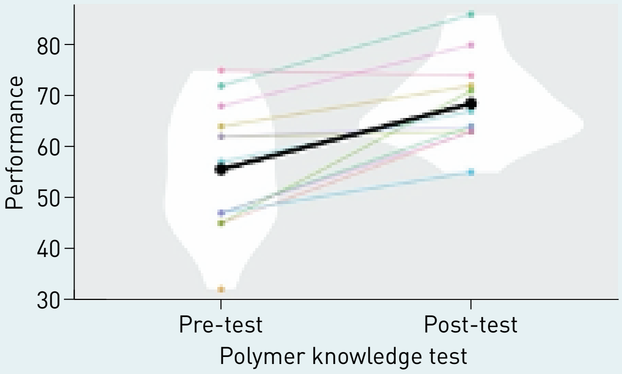
B: MODULE 1 COMPLETED



C: MODULE 2 COMPLETED



D: MODULE 3 COMPLETED



First, mean performance in the EKA was compared for all participants. A paired samples t-test was conducted between performance in the polymer knowledge pre-test ($M = 50.2$, $SD = 13.594$) and post-test ($M = 65.137$, $SD = 14.816$). The result was statistically significant, $t(72) = -10.336$, $p < .001$, $d = .999$ [.765, 1.233]. The effect size, $d = .999$, indicates than an improvement of

essentially 1 standard deviation was observed, meaning that approximately 84% of participants performed better in the post-test than the mean of the pre-test results. Next, pre- and post-test EKA performance was compared for participants who had previously completed the First Polymer Induction Moulding module 1. The result of a paired t-test conducted between performance on the EKA pre-test (M=40.125, SD=10.176) and post-test (M=50.429, SD=17.549) was statistically significant, t(6)=2.700, p=.036, *d*=.662 [.072, 1.251]. The effect size, *d*=.662, means that approximately 75% of participants performed better in the post-test than the mean of the pre-test results. Following this, pre- and post-test EKA performance was compared for participants who had previously completed the First Polymer Induction Moulding modules 1 and 2. The result of a paired t-test conducted between performance on the EKA pre-test (M=47.765, SD=13.5) and post-test (M=63.303, SD=15.629) was statistically significant, t(32)=6.908, p < .001, d=1.015 [.654, 1.376]. The effect size, *d*=1.015, means that approximately 85% of participants performed better in the post-test than the mean of the pre-test results. Finally, pre- and post-test EKA performance was compared for participants who had previously completed the First Polymer Induction Moulding modules 1, 2 and 3. The result of a paired t-test conducted between performance on the EKA pre-test (M=55.571, SD=12.271) and post-test (M=68.5, SD=8.544) was statistically significant, t(11)=4.779, p < .001, d=1.062 [.486, 1.638]. The effect size, *d*=1.062, means that approximately 86% of participants performed better in the post-test than the mean of the pre-test results.

4.6. Did the intervention have an effect on performance on the EKA post-test?

A final question of interest was whether the spatial training intervention had an effect on performance in the EKA post-test. To determine this, post-test performance between the experimental and control groups were compared, with variances in their pre-test performance being taken into account. First, a correlational analysis was conducted to see whether there was an association between performance on the EKA pre-test and EKA post-test. Figure 11 shows the results for both the control and experimental groups. Statistically significant strong correlations were observed, indicating that participants who scored highly on the pre-test tended to also score highly on the post-test. Similarly, those who performed relatively poorly on the pre-test tended to perform relatively poorly on the post-test.

An ANCOVA was performed to test the effect of the intervention by comparing performance on the EKA post-test between the control and experimental groups while controlling for pre-test performance. There was not a statistically significant difference in performance on the polymer knowledge post-test, F(1, 46)=1.15, p=.29, between the control ($M_{adjusted}$=67.7 [64, 71.3]) and experimental ($M_{adjusted}$=64.2 [61, 67.5]) groups. Unadjusted means for the control and experimental groups were 69.22 (SD=12.83) and 61.95 (SD=15.62) respectively (Figure 12). Therefore, no evidence was found that the intervention had an effect on performance in the FPT Skillnet online injection moulding theory module.

FIGURE 11 ▸ CORRELATION BETWEEN EKA PRE- AND POST-TEST

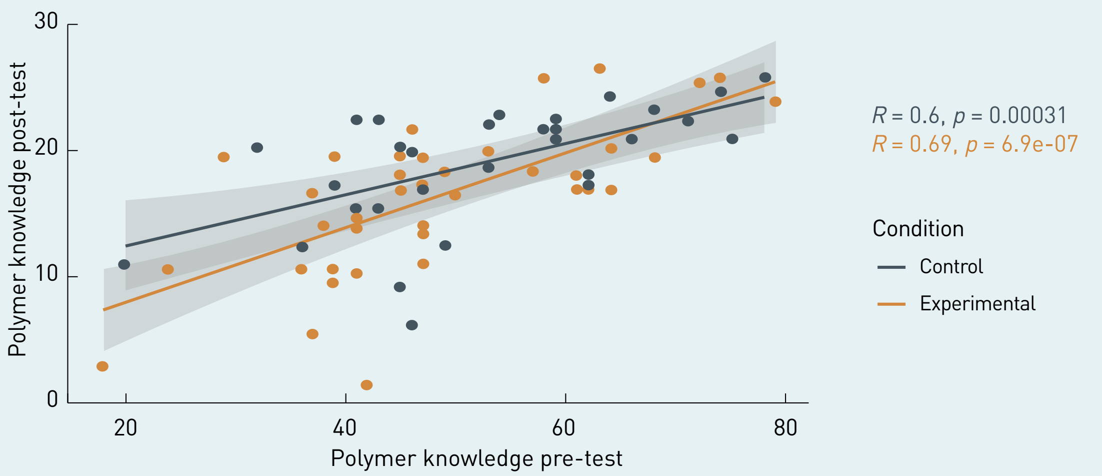


FIGURE 12 ▸ ESTIMATED MARGINAL MEAN PERFORMANCE FOR THE CONTROL AND EXPERIMENTAL GROUPS ON THE EKA POST-TEST AFTER CONTROLLING FOR PERFORMANCE ON THE EKA PRE-TEST

chapter FIVE

Qualitative Findings

As previously outlined, 20 participants from the experimental group were invited to engage in semi-structured interviews designed to gain insight into their experience with the spatial training intervention. Ten of the invited participants volunteered to take part in the interview process. Specifically, the interviews focused on the participants' perceptions and attitudes towards the spatial skills intervention in relation to how difficult they found the content, how feasible it was for them to complete the intervention whilst working, their levels of enjoyment and engagement with the intervention, and how beneficial they found the intervention. The complete interview protocol is available in at https://osf.io/9z4nt/ and the previously presented Table 2 provides information on each of the interviewees. The following sections present the main observations that were discerned from the interview transcripts in the areas of Difficulty, Feasibility, Enjoyment/Engagement and Relevance/Benefit.

5.1. Difficulty

There were a range of responses from the interviewees in relation to the levels of difficulty that they experienced. Some participants outlined how they found the intervention very familiar and easy to undertake.

> **John: No, I found it straightforward and easy to follow. I thought it was very good, actually, very good.**

> **Hermina: No [didn't find it difficult]. It was like, it would be like the questions at the end. It would be like loads of them. And at some stage you would be like hard keep the concentration to all of them. But I understood that, you know, you have to do like lots of questions there. But, you know, like there was nothing like too difficult that I wouldn't say. And I think that the progression was adequate.**

Others outlined how they found it confusing or frustrating to begin with.

> **Brian: I wasn't sure what to make of it at the beginning, but as I went into it, it started getting easier.**

> **Derek: Some of them I found it difficult to wrap my head [around], just in terms of getting my bearings. I did, I found that a bit difficult. It definitely didn't come naturally to me. For the most part, it didn't feel as though it did but it may have, I don't know.**

Some participants outlined that their previous experiences lent themselves to easily completing certain elements of the training intervention. Erik, for example, made direct links between the spatial skills training modules and his experience in the area of computer graphics.

> **Erik: I have a background in computer graphics, so it was easy for me to just move it around in my head. I was doing computer graphics in my life, so it was basically the Y and X axis. So it was very easy for me to get into it.**

Alan outlined how his second level educational experiences studying Design and Communication graphics and experience using CAD software helped when completing certain elements of the spatial skills training.

> **Alan: I think most of them were pretty easy. I'm used to doing, let's say from [Design and Communication Graphics] and stuff and just even from using CAD and SolidWorks, from having your 3D model and flipping it out to 2D prints.**

However, he went on to highlight that, even given his relevant previous educational experience and training, there were particular elements of the intervention that became more challenging, where he also found the online tutorials and physical building block resources to be useful.

> **Alan: But there was some [online exercises], one there. It became more complicated. It kind of put rotations and flips in. It was nice to get the practice and try to learn the methods from the videos.**

> **Alan: It was more when it was like your 3D shapes and then you are rotating it and you are flipping it and you're, right, what's the mirror from this angle or from this, this plane or this view, that I was, that I found having to put in that bit of effort and having the building blocks helped all right.**

5.2. Feasibility

The interviewees were asked to comment on their perceptions of how feasible they thought it was to complete the 15-hour intervention over a three-week period during their working week. The responses ranged from some of the participants managing to completely engage with the training whilst at work to others who found it difficult to find time for it. Erik for example could complete it whilst at work.

> Erik: Yeah, yeah, that's no problem on the nightshift I took some of the papers [workbook] to my work. I was doing them, doing my job, because on nightshift as a technician sometimes if I have some free time, I was just doing that in a lab, so that was no problem.

While Brian and Hermina, for example, had to complete the exercises at home.

> Brian: It wasn't viable when I was.... See I'm on my night shift and the day shift, the shift rotation. The shift when it was quiet, I could, or ideally I would do it at home because, you know, because it didn't suit. It could be a problem during the night. And then I wouldn't want to start it if I couldn't keep going on it. I think most of it was done at home.

> Hermina: It was a bit. Well, I would have to use to do it after work because, you know, it was kind of difficult. And also because I think, that, like I was saying, like, you have to focus. You have to do a module and you cannot be like really like this when people are just coming to you because then you lose like kind of the track of what you're trying to do. So it's more like, it's not that time demanding, but you really have to focus on what you are doing and just concentrate on that task.

Finally, due to personal and family commitments, others such as Ivan struggled to find any time to engage with the intervention.

> Ivan: Yeah, yeah, no, definitely the time, time was always an issue, you know, with work and family. So, yeah, I think it was really yeah. For me it was around that for sure, I think a total of 15 hours in general and yeah, it was fun to continue with. It was just getting the time, just sitting down for an hour or two, most of the time. That's... that's the problem.

5.3. Enjoyment and Engagement

The interviewees also varied in their reported levels of enjoyment and engagement when undertaking the spatial skills training intervention. The majority of the participants described enjoying the experience, whereby they found the modules to be engaging, challenging, a nice way to get back into learning again and commented on how the modules were a good mix of interactive online activities and hands-on, workbook and block-building based exercises.

> Derek: I thought the tutorials were nice, good bite-sized tutorials. I guess it did develop my skills spatially being out of college and education for a while. I know my results didn't reflect that. I think I got the same results as I did from the beginning at the end. But it was enjoyable back learning again I suppose.

> Hermina: Well, in general, it was really good. Like I really enjoyed it. I have to say as well that I really, I just had like, my visualising skills are good and I really enjoy it. I'm just a visual learner, totally. You know, it was interactive so that you could just like move things around. So it was really peaceful the way that it was delivered. So, yes, really aligning with what was the purpose. So it was very nice.

> Ivan: I think I enjoyed and benefited from this course. Well, I suppose it, the fact that, as I said, that I had to do something manually draw it on paper plus assemble all the models with the blocks that were supplied. That kind of part, I like to do things, you know, when I see the result of my work just to, even something with your hands, I like that part of it. So yeah, and look it, the first test I think I got 80% and the one at the end I got 90, so, it just, I suppose was a good result for me that I improved after all the work I put in, definitely got some benefit out of it.

> John: I found the course very good, I especially like the computer side of it. It was interactive I found it very good that way. There was no, there was no part of it that I didn't find interesting.

The negative comments in relation to enjoyment were related to the course being too drawn out, with too much content, taking too long to complete, or not being challenging enough for those who had high spatial skills from the outset.

> **Kevin: I suppose I enjoyed it. When I got into the spatial side I was enjoying it. Towards the end I was getting bored but at the mid-point I was really enjoying the spatial [training].**

> **Derek: I thought it was very time consuming and drawn out. You have to take time to do it correctly. And I found it frustrating that there was so much content to go through.**

> **Alan: If you already have some bit of spatial awareness and skills, it can be a bit monotonous. The first few, there could have been four or five pages and every section that you're like, ah come on now. That's just because I trained in it. So, yeah, maybe that's a biased view there.**

Some of the interviewees highlighted elements of the training intervention that increased their levels of engagement. For example, Ivan described how the workbook that was sent out to all participants to complement the online training, helped him to engage in the training, as this gave him something "manual" to complete and he felt that this "helped the process".

> **Ivan: And that the booklet that was sent out, I think, was a big help, where I found I had to do something, drawing myself, you know, manually that helped, I think, rather than just do everything online, but to provide that, you had to do something, you know, manually draw on paper. I think it helped the process.**

Chloe, who was from a non-technical background and was training and upskilling in the area of injection moulding, commented on how she found the spatial skills training to be enjoyable due to the fact that is was challenging and went on to explain how this positively affected her engagement with the training course.

> **Chloe: I think it's just that is the challenge in it. And so obviously with the workbook and that you have an idea of what way the rotation has happened and then when you get it right, it's like a pat on the back for you. But then when you get it wrong, you're kind of like, like a lightbulb moment, okay, so it's actually quite enjoyable, the challenge.**

Interviewer: Do you think that your enjoyment levels affected your level of engagement?

> **Chloe: I wouldn't say it affected the amount of time you engage with it, if anything it kind of helped me engaging in a little bit more, because obviously, if I didn't enjoy it, then I probably wouldn't engage as much as I did.**

5.4. Relevance and Benefit

There was a variance in the interviewees responses to questions on the relevance and benefit of the spatial skills intervention in relation to their industrial roles. Chloe, for example, made a direct link between the spatial skills training and the practical activity of loading a mould.

> **Chloe: I did, I did actually, it actually makes you stop and think like when it comes to, like loading moulds and everything like that, it actually does make you an awful lot more aware of your spatial skills that you have. Which is good.**

It is again interesting to note that Chloe's background is in a non-technical field and she has no previous academic qualifications in the area of engineering or manufacturing.

Other interviewees found it difficult to quantify the impact of the spatial skills training or to relate the training to their day-to-day work. Erik initially outlined that he felt that it was beneficial, but when asked to describe where in his everyday or working life, he outlined that he would maybe use some of the associated skills at work, but displayed a lot of uncertainty in relation to the specifics of where these skills might apply.

Interviewer: So did you find the spatial skills training beneficial to you?

> **Erik: Yes, I found it very beneficial, the training.**

Interviewer: So, in particular then, do you think that it would benefit you at work or would have an impact on everyday tasks that you carry out?

> **Erik: I don't know about everyday tasks, but I know it really made me think about some things. As a [person], I spend lots of time on the computer, so I know I will be using some of the skills at work, maybe in the future. I don't know, you know, the things are changing. So I would like to use them, some of them, but I don't know.**

Ivan also found it difficult to give a definite outline of the benefits of the spatial skills training for his day-to-day work but did comment that there was a benefit, "somewhere", to completing the training.

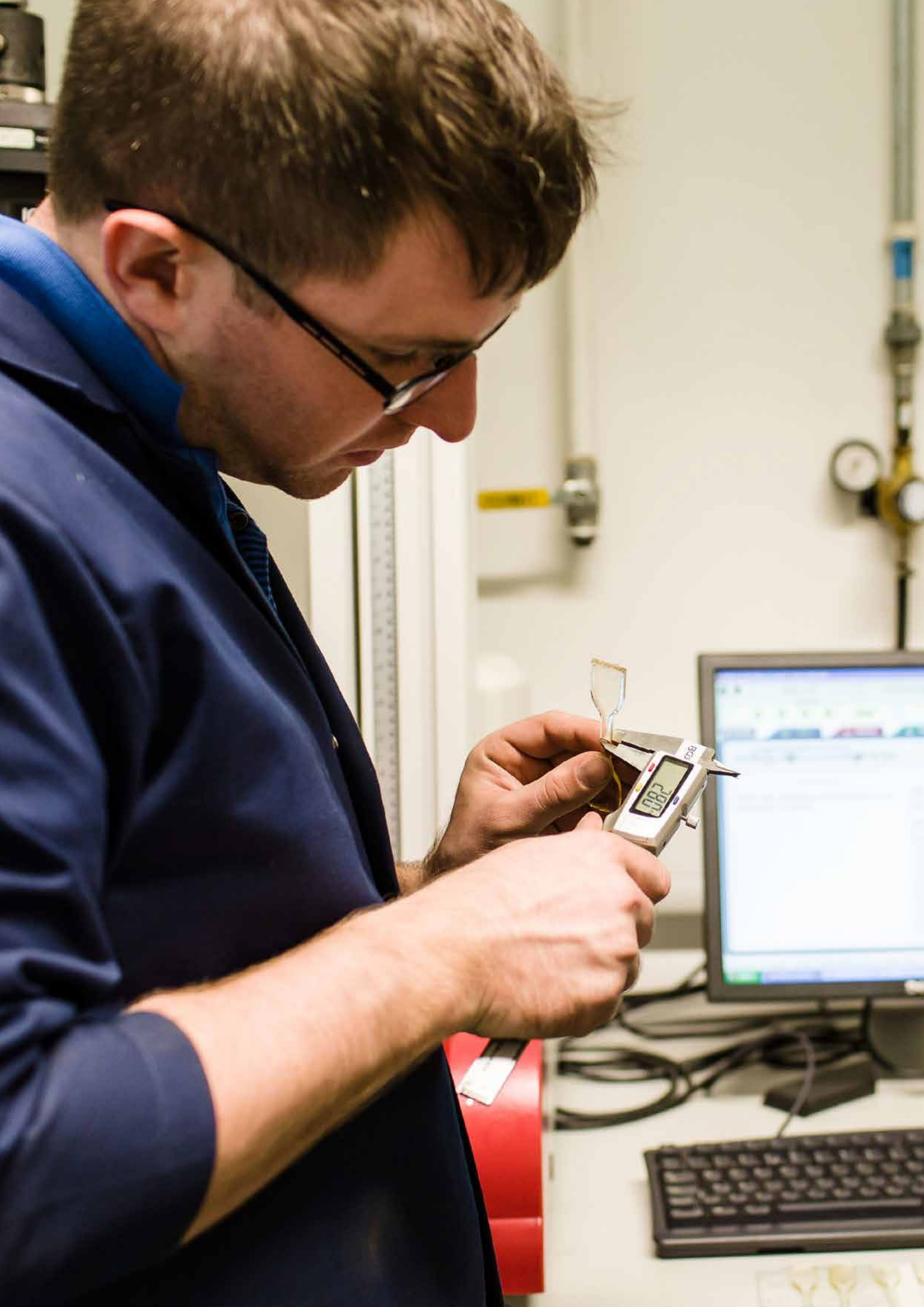
> **Ivan: Well, I think, just it's hard to quantify with work what benefit I got out of it really [apart from] the result between the two tests. What will I get out of it during my career and my life moving forward? Hard to say. I'm sure there is a benefit somewhere. Hard to say.**

Derek felt that due to the fact that he had previous 3D modelling experience, the spatial skills training was a level below his previous training and questioned the extent to which the training was of benefit to him. He did comment on how he felt it was beneficial but found it hard to quantify this benefit.

> **Derek: I don't know how beneficial it was. Maybe it was beneficial. I have done a lot of 3D modelling and stuff as well. So I guess that's kind of a step above spatial awareness. I suppose it was beneficial in some ways. I can't put my finger on it now. It's hard to quantify.**

Interestingly, Derek also commented on how the spatial skills training was useful as a preparatory exercise in advance of the FPT Skillnet module.

> **Derek: I think it definitely impacted [the FPT Skillnet module] in that it prepared me to set time aside and prepared me for online learning.**



chapter SIX

Discussion

Spatial ability, in particular the visualisation factor, is predictive of educational performance in engineering and more broadly in STEM. This has been found both longitudinally when spatial ability is measured at upper secondary level (Wai et al., 2009) and in case studies in third level engineering education (Alias et al., 2002; Mohler, 2008; S. Sorby et al., 2020). Spatial ability has also been found to be malleable and can be affected by specific interventions (S. Sorby et al., 2018; Uttal et al., 2013). Spatial skills training conducted in an academic environment has also been proven to be an effective means of increasing retention and success in early-stage undergraduate engineering education (S. Sorby et al., 2018).

The quantitative results of this study provide no evidence that spatial ability measured in adulthood, is associated with the level of formal education held by engineers or the amount of industry experience acquired. Further, no evidence was found to suggest that the completion of a self-paced spatial training intervention in an uncontrolled setting affected levels of spatial ability or that it impacted on subsequent performance in a disciplinary training module. However, this study did find evidence that discipline specific training, in the form of the online advanced injection moulding theory module delivered by FPT Skillnet, can significantly benefit related knowledge. No data was collected to determine whether this effect transfers to practice beyond performance in the FPT Skillnet module, but it would appear that in adult engineers who have industry experience and expertise, the more appropriate approach to professional development is disciplinary training rather than the targeted development of spatial ability.

While the quantitative results offer no evidence that spatial training in this population is effective, the qualitative findings offer important insight as to why this may be the case. An important point of discussion was that the participants found the intervention to be relatively easy, in particular those who identified links between the spatial training and their regular work activity such as CAD modelling. While some participants initially noted that the training could be difficult, this tended to improve over time. Considering this, it is possible that the intervention adopted, while appropriate for undergraduate engineering education, is not as effective for practicing engineers.

Another relevant factor relates to feasibility. The implementation of this study did coincide with substantial changes in work practices for many participants due to the current COVID-19 pandemic and associated restrictions

which undoubtedly affected participants' lives and engagement with the study. Given this, it is noteworthy that while some found time to engage with the intervention while at work, others found this difficult or tried to complete it at home and this interfered with family life and vice versa. It is unfortunate that insight on the feasibility of the intervention could not be gained under more typical circumstances, but it is unsurprising that finding time for something which could be seen as additional to mandatory work activities was difficult for participants at this time.

Despite all of this, the participants did note that the training was enjoyable. For some this came as a result of being challenged and a feeling that it supported them in preparing for taking the FPT Skillnet module. For others, the intervention aligned with the type of activity they enjoyed. It is also worth mentioning that, while difficult for some to specify, there was a general sense held by participants that the training was beneficial to them. Taking all these findings together, there does appear to be merit in continuing to investigate the relevance of spatial training for practicing engineers. It is likely however, that a more bespoke intervention would be needed, and further preliminary work is necessary to determine exactly when, particularly in terms of age and expertise, spatial training could have most utility. Prior to this, it is recommended that ongoing professional development activity concerning existing adult employees continues to focus and emphasise the promotion of disciplinary knowledge and skills.

Industrial employers have always played a key role in traditional apprenticeship education, and in recent years, they are having an increased role in the education of school leavers through initiatives such as the new Generation Apprenticeship higher educational award programmes. These programmes are industry led, where professional representative bodies such as the Irish Medtech Association and Polymer Technology Ireland direct the programme consortia. The consortia consist of industrial employer and higher educational institution representatives, and are responsible for the design, provision and continuous review of these educational programmes. The programmes were designed with school leavers and upskilling in mind. Initially, the uptake in these programmes were predominantly existing employees within companies looking to upskill. For the future feasibility of these programmes, it is proposed that companies should strongly consider recruiting school leavers to undertake these programmes for two reasons. Firstly, it will help employers to future proof their companies by developing this critical talent pipeline of young adults to respond to the skills requirements within their companies and increase and strengthen their workforces. Secondly, it is proving costly for companies to continue to pay existing employees their current salaries whilst they return to college to undertake a programme of study. A lower rate apprenticeship salary and the opportunity to "earn as you learn" is a very attractive opportunity for school leavers. This would also benefit industrial employers by fulfilling their future skills needs through effective investment and specific development of our nation's youthful human capital. Examples of these programmes of study are the Ibec led ordinary degree programmes of manufacturing engineering and polymer processing technology, that both lead to the attainment of an ordinary level engineering degree at level 7 on the National Framework of Qualifications. These programmes are QQI accredited degree programmes, just like traditional undergraduate ordinary degree programmes, whereby the main difference is that the majority of the time spent studying on these three-year programmes is "on-the-job" in the employing company's industrial setting. For the duration of this "on-the-job" learning, the student/apprentice is mentored by a suitably qualified industrial mentor whilst completing pre-defined learning outcomes that are assigned credits of learning. This is where spatial skills training within industry may prove to be of great utility as this form of training has already been outlined as beneficial for this demographic of early stage, post second level, engineering education students. With this in mind, the final recommendations of this study are outlined below.

6.1. Final Recommendations:

1. Industrial training of adult learners with previous engineering qualifications and/or industrial experience should remain focused on specific engineering knowledge training interventions.
2. Spatial Skills training has a beneficial role to play for STEM related career development and progression and this should be addressed in undergraduate engineering education programmes of study.
3. Where industry led programmes of study cater for school leavers, spatial skills development should be incorporated into these programmes.

6.2. Future Work:

1. Qualitative findings of this study outlined how participants found the spatial skills training intervention too easy but also commented on how they found it unidentifiably useful. Future work should investigate if a purpose designed, higher complexity spatial skills training intervention for engineering/manufacturing industrial employees could identify an area of utility for these participants.

2. Comments from the participants outlined how the spatial skills training intervention was enjoyable and helped to prepare the participants for undertaking the subsequent engineering specific industrial training module. Future work should investigate if a condensed, less time demanding version of the "low risk" training could achieve these similar results and in turn, be a useful preparatory prelude to industrial training programmes for those who have been removed from learning for a long period.

3. Increased numbers of school leavers are predicted to undertake industrial led apprenticeship programmes through the new "Generation Apprenticeship" higher educational award programmes. Future work should investigate the benefits of integrating spatial skills training into these programmes of study and analyse if similar previously defined benefits for early stage engineering education undergraduate students exist.

6.3. Limitations:

It is paramount that the work in this report be considered in light of associated limitations. Primarily, the conduction of this study at a time when participants were facing unforeseeable changes to their lives as a result of COVID-19 presented significant disruption. The exact scope of this is not clear, but it is worth noting that it is unclear how these results and findings would generalise or transfer to a time when such disruption is not present. Another limitation which occurred largely due to COVID-19 was that the many participants from the original sample of 136 withdrew participation from the study such that the final sample of 80 had significantly less statistical power to detect smaller effect sizes. Finally, in an effort to implement this study in a way which could be employed at a larger scale had the results indicated a benefit of the spatial training intervention, the administration of the PSVT:R and intervention was notably different to how these have been used in previous work. Specifically, where these tests have traditionally been used in controlled academic settings under a strict timetable, in this study participants engaged with them at a self-paced rate to suit their schedules. This, while having the advantage of mirroring any potential future implementation of scale, has the disadvantage of introducing additional variables and factors not found in other work and so should be acknowledged in the interpretation of findings.

chapter SEVEN

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