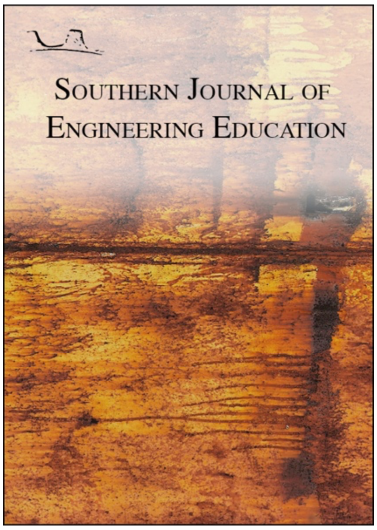

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Engineering practices observed in South Asia

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The development of engineering skills in Africa could be improved by learning from experiences in South Asia where research has exposed significant weaknesses in the engineering education ecosystem. Research has shown how socio-technical interactions that involve collaborations with other people dominate the work of professional engineers. In contrast to wealthy, developed countries, societies in the Global South are often characterised by complex patterns of social behaviour where perceived reputation, socio-economic status, caste, tribal identity and language strongly mediate power structures and hence collaborative performances such as engineering. In addition, several environmental factors such as the local economy and business practices, labour market, education, weak social security, low trust in strangers, climate and geography all influence the ways that engineers practice in their firms. These factors, coupled with pragmatic responses within firms, and knowledge gaps such as incomplete perceptions on labour costs, make it much harder for engineers in South Asia to generate similar levels of performance as in wealthier countries. Engineers' salaries and the cost of engineered goods and services of equivalent performance and quality may serve as objective indicators of engineering performances. This paper concludes with suggestions for engineering educators in the Global South to help a greater proportion of engineering graduates to become competent novice engineers in local enterprises with these socio-cultural and economic complexities.

Keywords: engineering practice; social culture; development studies; engineering education; Global South

Introduction

Engineering is critical for social and economic development, to provide goods such as energy, water supplies, sanitation, transport, communications, fertilizers, and food processing. The development of improved engineering skills in Africa is critical to meet rising expectations across the continent.

Echoing observations in Africa (e.g., Senzanje, 2003), South Asian[1] engineers are struggling to meet these expectations despite increased investment in engineering education

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[1] South Asia includes India, Pakistan, Bangladesh, Sri Lanka, Nepal, Sikkim, Bhutan, and the Maldives.

over the last few decades. The cost of engineered goods and services of equivalent performance, quality, durability and reliability tends to be higher than in wealthier countries (Trevelyan, 2014). Engineered artefacts should enable people to be productive, to do more with less effort, time, materials, energy, uncertainty, health risk and environmental disturbances. However, even though productivity in India has improved more rapidly than other countries in the Global South, Indian productivity is still less than a quarter that of wealthier countries[2], despite the widespread availability of new technologies (Manyika et al., 2015). Furthermore, a large proportion of South Asian engineering graduates, as high as 80% by some estimates, are considered unemployable as engineers (Tilak & Choudhury, 2021). Those who find employment mostly earn about 15% of the starting salaries for engineering graduates in Australia (Kaspura, 2019; Tilak & Choudhury, 2021). These significant differences in outcomes raise questions about the effectiveness of engineering education, and efforts to improve education outcomes in Africa may – depending on the context – benefit by learning from South Asian experiences.

Engineering education curricula are largely standardised globally, using similar if not identical texts, often in English rather than in the local national languages. So far, 29 countries have ratified the Washington Accord that prescribes attributes of professional engineering education programmes and many more use similar criteria to accredit their education programmes (International Engineering Alliance, 2021). Such broad standardisation reflects an implied assumption that the knowledge required by engineers is universally applicable. However, the differences in outcomes suggest that this assumption is questionable.

As Figure 1 suggests, even a superficial visual comparison can challenge the assumption of universality in engineering practices. Widely reported difficulties encountered by engineering workers who migrate from one country to another can also lead one to question the validity of this assumption (e.g., Friesen, 2011; Shan, 2012; Trevelyan & Tilli, 2010). If engineering practice were substantially similar between countries, engineering workers would readily gain employment after migrating. However, the objective performance indicators mentioned above, coupled with research observations from the Global South, help demonstrate significant differences between engineering practices there compared with those in higher-income countries such as Australia.

[2] http://wdi.worldbank.org/table/2.4.

Figure 1*: Residential construction in Melbourne (left) and Islamabad (right), November 2022. (Photos by author)*

In this paper, I argue that critical aspects of knowledge required by engineers are location dependent. Even though the available evidence is limited, there is enough to justify further research on local engineering practices in different countries and settings and to start adjusting some aspects of professional engineering education programmes.

While South Asian engineers mostly succeed as migrants in countries like Australia, in their home environment their counterparts struggle to achieve similar performance levels, as evidenced by the high costs of engineered services such as safe drinking water, construction, electricity and manufacturing (Trevelyan, 2013, 2014). Costs of engineered goods *of equivalent design, quality, durability, performance and reliability* tend to be higher in South Asia than in Australia, a significant impediment holding back economic and social development. For example, safe drinking water can cost 10 times more than in Australia because it mostly has to be manually transported because water distribution pipes in most cities are contaminated with faecal bacteria. Electricity, at the point at which it performs useful work, can cost four times more (Trevelyan, 2013), because of the need for generators and other backup power sources to maintain supplies through frequent interruptions to the grid supply and also appliance inefficiencies. One notable exception is telecommunication services which can be less expensive than in wealthier countries while providing comparable service quality (Trevelyan, 2013). Similar observations have been made by Sachs and others, for example commenting on the relatively high cost of engineered agricultural inputs such as fertilisers (Sachs, 2005).

Some readers might argue that manufacturing centres established in India (in particular) by large multinational firms contradict the observations on the cost of engineered goods. Would these firms invest in India if the cost of their business was higher than in wealthier countries? Certainly, many firms in wealthy countries have outsourced parts of their engineering operations to India and other countries where certain activities such as drafting can be performed at lower cost because of the low hourly cost for hiring drafters, programmers, finite element mesh designers, and other specialised technical workers. However, the costs and difficulties are often underestimated (Leonardi & Bailey, 2008). Such investments may also be strategic, for example to establish a foothold and gain first-hand experience in what is widely expected to be a rapidly growing market in the future. Indeed, many of the observations reported in this paper came from such a manufacturing centre, a firm established with significant offshore investment which has been recognised as one of the leading firms of its kind in India. Yet the same challenges influencing the high cost of engineered goods were also present in this firm.

Several unanswered questions motivated two decades of research on engineering practices by my students and myself in Australia and South Asia, including the following. Can the performance difficulties experienced by engineers in their home countries be part of the explanation for the relatively high costs of engineered goods and services? Do engineering performance difficulties mainly arise from environment factors beyond their control? Is it possible that engineers could respond to these factors with significantly improved results?

From 2003 onwards, my students and I have interviewed and observed engineers in India and Pakistan with the aim of comparing their observations with detailed descriptions of engineering practices in wealthy countries from the research literature. We expected that this would expose differences between South Asian engineering practices and those in other countries. However, as Barley (2005) wrote at the time, little was known about technical work. Only about 20 detailed observations were available (e.g., Bucciarelli, 1994; Lam, 1997; Vinck, 2003; Zussman, 1985), and substantial effort was needed to find them (Trevelyan & Tilli, 2007). Therefore, the scope of investigation had to be widened to include engineering practices in Australia and other relatively wealthy countries.

Subsequently, many researchers have begun to address the significant weakness in our knowledge of varying international engineering practices (see Jesiek, 2018; Mazzurco et al., 2020). However, we still have only a few research observations of engineering practices from the Global South (Coelho, 2004; Domal, 2010; Kusimo & Sheppard, 2019; Matemba, 2020; Nan & Bocong, 2018; Trevelyan, 2013, 2022; Zhu, Hu, Li, Zhang, & Li, 2021; Zhu, Hu, Zheng & Li, 2021). Several of these represent substantial and detailed research contributions. The paper draws on these contributions to show that engineering practices in South Asia differ significantly from practices in Australia and other wealthier countries. Furthermore, even this limited evidence base helps to explain the outcome differences described at the start of this paper and how African engineering might be reshaped in future.

Through a chance encounter with an importer of specialised high-value engineering equipment, I identified a small number of expert engineers in South Asia who were readily distinguished by high salaries, comparable with salaries for engineers in wealthy countries. Since remuneration can be a sensitive topic, this information usually emerged from casual conversations after formal interviews had concluded, being a more conducive atmosphere for sharing confidential information. Not every participant felt they could share their remuneration details.

The importer's engineering customers recognised that his American products provided substantially greater value than competitors because superior technology enabled superior performance with easier operation and maintenance. These engineers had managed to persuade their employers to purchase the more costly American products. As in many countries, procurement is a specialised function within an engineering firm: procurement staff know how to obtain the best possible purchase terms, and usually the decision is based almost entirely on purchase price. Even senior engineers may have little or no influence over their decisions (Domal, 2010). One the importer's customers explained how he influenced the purchasing department in his firm:

> I asked the supplier to draft a purchase specification that would exclude the competing products, and the purchase department accepted that: they did not have sufficient knowledge to question it. Then they could confirm for themselves that the US-made equipment that I had recommended was the only product complying with our requirements (interview by author).

Another attribute characterising these engineers was their ability to think about their contributions to the firm in terms of commercial value. For example, this engineer reflected on the relative cost and contributions of his product development team.

> It is nowhere near what I am saving them. I think there is a factor of 50 there … This was a very novel concept within the company. But I use the same concept on myself: if I am being paid that much, that's how I must perform. I do these things internally for myself, for my own justification, for my own ego, but nobody asks me to do that (interview by author).

The reason for their high salaries became evident once their contributions to their firms were identified. These engineers had become critical to their respective firms' success and therefore they were paid sufficiently well that they would not have any financial incentive to relocate to a wealthier country where engineers could expect higher remuneration.

Finding these expert engineers was a significant development in the research because it exposed the relevance of the marginal product theory of wages from labour market economics. This well-supported theory predicts that remuneration will reflect value generation. Engineers who earn more do so because their firm perceives that they generate more economic value (Trevelyan & Williams, 2018). Therefore, salary levels can help us assess the relative economic contributions of engineers, an objective performance measure for engineers in different firms and countries. We can therefore conclude that Australian-based engineering graduates generate more economic value than their Indian counterparts.

This does not imply that Indian engineers are less capable or intelligent than their Australian counterparts. Instead, it tells us that engineers in Australia, including South Asian migrants, are more able to generate economic value for their firms because engineering practices are different. Indian-born and educated engineers migrate to Australia and other wealthier countries in substantial numbers, and after a period of adjustment perform comparably with local engineers because they follow similar practices. The fact that the expert engineers in South Asia were earning salaries comparable or higher than engineers in Australia tell us that they somehow managed to work out practices that enabled them to generate comparable economic value in their home environments. Their firms were able to supply goods and services equivalent to the best imported alternatives.

The relative cost of engineered goods and services of equivalent design, quality, performance, durability and reliability may offer another objective outcome measure that can indicate relative levels of engineering performances. If we can understand how these cost differences are related to engineering practices, it might be possible to help firms and utilities reduce these costs. By reducing the costs, engineers can generate greater value and, ultimately, will benefit from higher remuneration. Studying local engineering practices could also fill knowledge gaps among engineering educators, most of whom lack recent experiences of commercial engineering practices (see Cameron et al., 2011).

Therefore, this paper first reviews what we have learned from research observations about socio-technical interactions between engineers and others that form the dominant components of professional engineering practice. These are also the main aspects of practice that are location dependent. Next, the paper identifies environmental factors affecting engineering practices that cannot easily be changed. Several research observations help to identify location-dependent aspects of engineering practices and help to identify knowledge gaps and practices that might be changed. Observations of expert engineers provide evidence that engineers can change local practices and acquire the knowledge needed to provide engineered goods and services equivalent to imported equivalents. Finally, the paper speculates on ways that engineering educators might be able to help graduates benefit from these expert engineers' experiences.

The literature describing engineering practices based on workplace research studies still consists of a relatively small body of knowledge, perhaps a few hundred books and articles. It is small in relation to engineering education research as a whole. Further, there are very few research studies on engineering practices from the Global South. Even so, these accounts raise many relatively complex issues spanning business, finance, anthropology, economics and psychology. A single journal article only permits space for references to a small selection of relevant literature, so the reference citations in this paper should be regarded as starting points for reading rather than a definitive list.

Socio-technical aspects of engineering practice

There are aspects of engineering with universal applicability relying on knowledge derived from science and mathematics such as the properties of materials and calculation methods that predict the behaviour of engineered artefacts and systems. Engineers frequently use computer software that makes it easier to use such knowledge in their daily practice. This knowledge and the related computer software are universally applicable, explaining why engineering education curricula are largely standardised worldwide, and with similar texts.

Implicit and tacit knowledge, such as tightening nuts and bolts appropriately, making reliable soldered electrical joints, pouring reinforced concrete, debugging memory leaks in software, and implementing earthing and lightning protection, largely untaught, is equally universal and applicable anywhere.

However, another major aspect of engineering practice is not as universally applicable. A growing body of research evidence reveals how socio-technical interactions between people enacting a range of collaborative performances lie at the core of engineering practice. For example, informal technical coordination, gaining willing and conscientious collaboration from others with an agreed time schedule and without relying on organisational or other authority, appears to constitute a significant proportion of the work of professional engineers (Anderson et al., 2010; Blandin, 2012; Jesiek et al., 2019; Trevelyan, 2007; Vinck, 2003, 2019). One explanation for the relative prominence of this activity derives from the distributed nature of expertise: knowledge is distributed across numerous participants, both engineers and others (Trevelyan, 2010a). Professional engineers frequently engage with others across organisational and discipline boundaries (Asplund & Flening, 2021; Jesiek et al., 2018; Jesiek et al., 2021) and also adopt persuasive communication practices to secure resources and advocate for particular interpretations of evidence (Coso Strong et al., 2022). At the same time, many engineers regard this socio-technical activity as 'non-technical' or 'not real engineering', even as an interruption to their 'real engineering' work (Bailyn & Lynch, 1983; Perlow, 1999; Perlow & Bailyn, 1997). Trevelyan (2007) noted that even highly experienced engineers might not be consciously aware of coordination activity. Engineers, at all stages of their careers, are constantly building and maintaining their networks of personal contacts – suppliers, customers and clients, sources of technical expertise, regulators, people who know where to find experts, and so many others. Neither the network nor the social and cultural skills needed to create it and navigate it successfully are easily transferrable to a new country, even a new firm or industry.

Quantitative estimates of the proportion of time that professional engineers spend on socio-technical interactions with other people, including face-to-face, telephone and teleconferencing, through text, and through human-readable data in information systems, vary between about 40% and 90% (e.g., Tenopir & King, 2004; Trevelyan & Tilli, 2008; Williams

& Figueiredo, 2010). In other words, socio-technical interactions with other people dominate professional engineering practice. Seeking human-readable information is another significant component, typically 5 to 10%, and might also be considered as a form of socio-technical interaction (Tenopir & King, 2004; Trevelyan & Tilli, 2008). Therefore, it would be surprising if such interactions were not influenced by the culture(s) of the host society and organisation. In contrast, so-called 'technical' work, solitary cognitive performances that require interactions with abstract objects, usually mediated by information systems, form a relatively much smaller component of practice. Engineers typically spend 5 to 20% of their time on this activity, including design, calculations and modelling and most spend a negligible proportion of their time interacting manually with physical objects (Trevelyan & Tilli, 2008; Williams & Figueiredo, 2010).[3]

Therefore, the central part of engineering practice, socio-technical interactions with other people, is neither easily transferrable nor relies on universally applicable skills. This can explain why engineering practice is not universal, but may be highly specific to a particular country, industry or firm.

Other aspects of engineering practice are also specific to a particular location or setting. As Latour (2005) has explained, localised knowledge, much of it embodied in the physical infrastructure of a workplace, is usually more important in creating workplace competence than the particular competencies of an individual. For example, operating a profitable business in a traditional street market requires implicit knowledge acquired through years of experience, most likely passed on from parents to children. On the other hand, a supermarket has many levels of established structure: the layout, shelves, barcodes, packaging, labels, price tags, checkout terminals and the back-end logistics and information systems that instantly create competence among young workers who may not have even finished school. In the same way, engineering firms provide physical and virtual infrastructures, IT systems and tools (mostly as software) that enable competence among engineers (Petersen & Buch, 2016). As we shall see, it is the combination of socio-technical skills, access to knowledge and expertise through professional networks, business processes, infrastructures, IT systems and tools that distinguish engineering workplaces in India from those in wealthier countries, and these enable engineers based in wealthier countries to generate far more economic value.

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[3] The video 'What do I do as a mechanical design engineer?' (https://youtu.be/pX03H1oeyN0) provides an entertaining explanation supporting this finding.

Environmental factors

Many factors influence the practice environment for engineers and cannot easily be changed. They shape pragmatic responses by engineers, some of which will be explained later in the paper. They include national and organisational culture, geographic location, climate, labour market and education, governance, and the local economic environment which is itself shaped by other firms responding to similar local and international influences. In contrast, engineers can influence practices implemented within a particular firm or organisation.

At a superficial level, the work of engineers in South Asia can seem much the same as in any other country. A typical working day involves email correspondence, phone calls, meetings, site inspections, and some solitary technical work, most often through sketches, drawings or computer information systems. Examination through a research lens developed in one country can attenuate, even hide the influence of another country's culture, geography, language and economic environment (e.g., Zhu, Hu & Zheng et al., 2021).

Many have argued that the cultures of the host society and firm strongly influence economic performance. However, since we are constantly immersed, culture can be challenging to observe, primarily by noticing differences between cultures. Cultural influences on firm performance have been extensively researched since the 1980s.

However, Chatman et al. (2016) recently argued that studies of organisational culture, in particular, need to be reconsidered because they have lacked construct validity, and researchers have drifted from academic enquiry towards lucrative industrial consulting. Some have even argued that observing culture is 'inherently subjective and requires a researcher to have extraordinary sensitivity an almost preternatural capacity to think, feel and perceive like a native' (Chatman & O'Reilly, 2016, p. 8). Writers have confused the concepts of 'organisational climate' (shared perceptions on policies, practices and rewards); 'social culture' as underlying assumptions and beliefs (conscious and unconscious); norms and values about appropriate behaviours; artefacts reflecting these (such as clothing, language, symbols); and organisational practices. There is still only loose agreement among scholars on what constitutes culture.

Hofstede (2011) and Trompenaars & Hampden-Turner (2021) both proposed measures that can differentiate national cultures, yet both approaches have been criticised, citing weaknesses stemming from data sets accumulated in the course of business consulting work, mainly with managers working for larger companies (e.g., Jacob, 2005). For example, neither considered the influence of religion except to assert that some religions place a different emphasis on the need to change or improve the conditions under which people conduct their lives. However, both schools of thought have provided ideas that can help distinguish the influences of host cultures on engineering practices. Tellis et al. (2009) studied the influences of national and organisational culture, government policy, labour and capital on the wealth of firms and nations, concluding that organisational culture was the most decisive influence. Their paper (Tellis et al., 2009) reflects, in part, the interests of their audience, marketing researchers and practitioners. Also, reflecting earlier observations by Chatman et al. (2016), Tellis et al. (2009) chose organisational culture measures that include attitudes and practices such as willingness to cannibalise profitable assets for higher future profits (an attitude), and empowering product champions (a practice).

Tellis et al. (2009) also recognised, though relatively simplistically, the influence of geography on regional GDP in terms of distance from the equator. Mellinger et al. (1999) devised a more comprehensive quantitative model to account for geographic influences on regional GDP, including factors such as proximity to the sea and climatic zones. For example, after correcting for purchasing power, they assessed the average GDP in temperate coastal regions as 18 times higher than non-temperate zones far from the nearest coastline. The influence of geography is particularly relevant for the economic development in the Global South, explained qualitatively in some detail by Kamarck (1976) in his report for the World Bank. For example, human muscles release heat energy that has to be transferred to the environment. At higher ambient temperatures, heat transfer is slower in the absence of air conditioning, imposing finite limitations on physical exertion (e.g., Zhu, Wang, Zhang & Wang, 2021). Some economic development impediments in tropical countries identified by Kamarck (1976) have since receded in significance, particularly diseases such as malaria, dengue and trypanosomiasis because of medical interventions and control measures to reduce the prevalence of insect carriers.

A large proportion of South Asian people working in engineering enterprises live in urbanised communities where indoor night temperatures exceed the neutral temperature for human sleep, above which metabolic heat cannot be lost to the environment fast enough to maintain normal body temperature (approximately 30 °C with a fan, 27 °C without a fan (Hansen & Soebarto, 2019; Khosla et al., 2021; Lan et al., 2017)). I have conducted numerous indoor temperature observations in the course of designing novel air-conditioners to provide energy-efficient cooling devices for South Asia. The overwhelming majority of people in South Asia who cannot afford artificial cooling, therefore, may be suffering from sleep deprivation for months at a time, particularly in the monsoon season when water coolers are ineffective. Under these conditions, capacity for work, both physical and cognitive tasks, is significantly reduced (Day et al., 2019), though objective measurements on work capacity are only available from research institutions where participant sleep quality is assured. Many parts of Africa experience similar climate conditions as in South Asia.

Several other challenging environment factors are mentioned below, including levels of trust in strangers, the local business and economic environment, availability of social security and welfare, labour markets, education, governance, and legal systems. When seen in combination, it can be hard to see how all these adverse factors could possibly be overcome. Yet as we shall see, at least a few engineers have successfully managed that.

Research methods

This paper draws on interviews and field studies conducted by my students and myself (Trevelyan, 2016), and also draws on extensive evidence available from other studies, particularly PhD theses based on observations in the Global South. Coelho (2004) studied engineers in an Indian water utility, and Domal (2010) studied mechanical engineers in a leading automotive component manufacturing factory in India, comparing them with similar engineers in Australia. Some data from Africa has recently become available (Kusimo & Sheppard, 2019; Matemba, 2020).

Between 2003 and 2013, my students and I conducted 330 qualitative interviews lasting 90 to 120 minutes each, which contributed data on engineering practices in Australia and South Asia. Ten field studies conducted by students helped to triangulate interview data (details appear in Trevelyan, 2013; 2014; 2022). All South Asian participants identified as male, while a few Australian participants identified as female.

I have also drawn on my experience practising as an engineer in Australia, UK and Pakistan since 1971 and teaching engineering from 1975 till 2016. I have directed a small business enterprise in Australia and Pakistan since 2007, and have gained insights into those countries' economic and regulatory environments. Interactions with other South Asian firms have also helped me understand the similarities and differences compared with Australia. For example, while there are differences in social culture between India, Pakistan, and other South Asian countries, they are minor when comparing with cultural and social practices in Australia. Therefore, this paper refers to 'South Asian' participants and only identifies specific countries when necessary.

Qualitative data analysis followed conventional interpretive methods (Charmaz, 2014; Huberman & Miles, 2002; Miles & Huberman, 1994; Patton, 1990; Strauss, 1987). First-hand experience of engineering practices in Australia, UK and Pakistan and extensive visits to engineering operations in several other countries enabled theory construction beyond the interview and field study data (Charmaz, 2014). For example, frequently occurring patterns of technical coordination to enact distributed expertise in engineering enterprises were not explained by any of the participants (Trevelyan, 2007, 2010a). These concepts emerged from data by repetitive reading and reflection on the data, coupled with personal experiences of practice and living in the respective countries. Subsequent independent research has provided supporting evidence, with some cited above. Several of the students conducting research interviews also have had extensive engineering practice experience. Discussions of the early findings with participants and others, experiences from running businesses in Australia and Pakistan, and literature from organisation science, labour market economics and development economics have helped me further develop the ideas presented in this paper.

Factors affecting engineering practice

Interview data revealed several significant social and cultural factors that influence engineering practices. The following sections describe several factors that seemed to be more influential in making it difficult for engineers in South Asia to generate results that could be expected in Australia and other wealthy countries. While they are described in separate sections, they are all interconnected and their influences cannot easily be untangled.

The data also revealed a wide range of practices within each country. While activities in some engineering firms in South Asia follow practices similar to those in firms in Australia, others exhibit practices that are vastly different. These variations indicate the need for a large number of observations in different settings, industries and countries in order to position practice attributes within ranges that can be encountered within a particular country.

Trust in strangers

On visiting an engineer's office in South Asia, it is not unusual for a researcher to be seated alongside a visitor on a couch or armchair who seems to have no obvious connection with the firm's business. With relatively high social status within the firm, many engineers face a seemingly endless succession of visits during the working day from distant relatives and extended family members seeking employment for sons, daughters or other relatives. They may be people whom the engineer cannot recall, but the mention of certain family members by name means that the visitors cannot be ignored. These visitors may sit silently for hours while the work of the day proceeds, seemingly without reference to the visitors at all. If not in the office itself, the visitors will patiently wait in ante-rooms, or in the immediate vicinity outside (Coelho, 2004).

Mistrust of strangers can help explain this observation. South Asian societies typically exhibit low levels of trust outside family and in-groups (Balliet & Van Lange, 2013; Frevert, 2009; Jacob, 2005; Nadeem, 2013; Ward et al., 2014). In-group membership depends on reputation, socio-economic status, caste, tribal identity and language (Waris & Kokab, 2017). Many firms are controlled by a powerful family, and positions of authority are often reserved for family and in-group members. A 'family' can include non-relatives. Such an extended family is usually based on long-lasting and intimate ties with others who, for all intents and purposes are considered to be family members, even to the extent that males are admitted to female-only parts of the household as if they are brothers from the same father. Therefore, gaining employment may rely more on family connections than qualifications and experience because family membership provides sufficient trust for a measure of delegated authority. Among engineers, a given level of technical competence cannot be presumed. This practice can also promote firm loyalty because of the relative difficulty of securing employment in other firms where family connections may be more tenuous or non-existent. Similar patterns can influence public sector employment below the most senior levels where entry requires high performance in tightly controlled public service examinations. However, in the public sector, support from and loyalty towards powerful local political actors can also be a requirement, whether their party is in office or not.

In contrast, a greater level of trust in strangers in Australia permits recruitment selection based more on personal attributes such as workplace competency and relevant technical experience. However, family and other personal connections also significantly influence recruitment at many Australian firms.

As an example, this South Asian engineer explained his low level of trust in outsiders, especially 'vendors' – small roadside enterprises to which some manufacturing work is outsourced (Domal 2010).

> The people who work directly for me at [this firm], by and large, they are all honest, hard-working people. 60% of my vendors are dishonest! In England you assume that someone is telling you the truth unless proved otherwise. In this country you assume that he is lying unless proved otherwise. I think that's how you start and it's something you have to deal with on a day-to-day basis and it wastes a lot of resources, time. Misrepresentations, false statements, what have you like to call them, it has become a way of life in this country, and I don't see it changing in my lifetime (interview by author).

Social welfare

Another environment factor influencing engineering practice is the availability of social security and welfare. In societies with weak or non-existent social protections, the need for job security can be a more powerful behavioural influence. In South Asia, personal catastrophe may only be a short step away, out of sight around an unexpected corner. Disease or accidental injuries requiring costly medical attention, an unintended insult towards a senior, or simple mistakes arising from ignorance can suddenly terminate employment and the income security that comes with it. Fear of falling, to become one of the vast masses of urban poor, is a powerful emotion that lurks close to the surface of the psyche. Domal (2010, p. 182) described

> ever present, enormous and unresolvable social disparities between the shop floor workers, the day labourers, representing the mass of humanity clutching to a precarious day-to-day existence, on the one hand, and the engineers and managers representing the middle and upper-class social elites. These disparities seem to bring intensity to otherwise ordinary differences of opinion which is seldom experienced in the Australian context. Further, it is possible that the hopelessness of ever resolving the social disparities is reflected in the apparent lack of enthusiasm in Indian engineers to solve issues in the factory which could be resolved.

Losing one's job or acute illness in Australia can still be a traumatic event for many but is rarely a catastrophe because there are strong institutional support structures in Australia including high quality physical and mental healthcare systems coupled with economic support.

The social disparity between engineers and shop floor workers is much less, so much so that shop floor workers can and do make significant contributions to engineering decisions. For example, this Australian engineer explained how his firm ensures that early-career engineers acquire practical knowledge from shop floor supervisors.

> A wise construction boss will make sure that a young engineer has a highly experienced foreman on his site. The experienced foreman will be teaching the engineer how to do the project management, a kind of reverse mentoring. Older foremen with the right skills get a tremendous thrill from doing this kind of thing especially when they're explicitly asked to do it (interview by author).

A reader might suggest that demonstrating superior workplace competence would provide employment security. However, research interviews by the author demonstrate that overt displays of superior work performance can undermine social relationships, disrupting knowledge sharing through social networks, especially in a culture where workplace seniority (duration of service) is valued more highly than competence.

Income supplementation in government service

Government service in South Asia is characterised by significant social responsibilities and low salaries, imposing significant constraints that shape engineers' practices. Coelho described engineering work in a government water utility lurching uncertainly towards a degree of privatisation (Coelho, 2004, 2006), revealing how engineers are not only responsible for managing daily operations but, unlike their Australian counterparts, are also responsible for revenue collection. Interviews by Domal (2010) yielded insights into some of the tactics used by engineers responding to revenue collection targets that can exceed 80%. Engineers may resort to breaking pipe connections to insert flow restrictors to help persuade reluctant customers to pay their bills, as this engineer explained:

> People will be paying electricity bill, cable bill everything but water they won't be paying … until and unless we go there … people will be … sometimes we block the sewage connection also … some of the customer they don't pay even if you disconnect the water supply line they won't pay … so ultimately we have to block their sewage system. (Domal, 2010, p. 220)

In doing so they unintentionally enable sewage contamination to seep into the water pipes through poorly restored joints that are often lying in open sewers alongside urban streets because the water supply pipes are only pressurised for a couple of hours every two or three days. While this is a pragmatic engineering policy (Taylor et al., 2019), one of the consequences is that piped water connections throughout South Asia tend to have faecal contamination, causing a high incidence of stunting, permanent intestinal damage to infants caused by repeated diarrhea episodes (Bain et al., 2014; Cumming & Cairncross, 2016).

Water supplies also affect workers' health, particularly lower-paid clerical and manual workers who may be unable to afford effective water filtration at home. No one can escape occasional gastric infections, but without safe drinking water at home, these are more frequent and debilitating and can cause stunting in children (Cumming & Cairncross, 2016) and significant absences from work, reducing productivity.

Engineers working in a South Asian public service utility face particularly acute dilemmas (Coelho, 2004; Domal, 2010). Accountable to a district engineer, they have to work with many powerful local stakeholders including politicians, business owners and wealthy residents, with occasional delegations or organised protests from less wealthy residents. Their mobile numbers are often widely circulated unofficially, so an endless succession of calls punctuates the working day until late in the evening. Working in a bureaucratic organisation that cannot respond quickly to economic and market shifts, engineers can find it impossible to satisfy demands from powerful actors with allocated labour and official spending constraints. Low official salaries leave no room for flexibility, so many engineers pragmatically respond to urgent service requests from wealthy stakeholders by accepting unofficial payments that some would see as bribes. Some eschew requesting such payments, accepting them only when offered voluntarily. Discovering illegal connections, therefore, can open up significant opportunities to supplement informal funds that can then be used to satisfy requests from other powerful stakeholders who may not offer payment, or may not have the means to pay. Tracing such connections can be challenging (Figure 2) and most are hidden underground. Nevertheless, the pursuit of such connections can open still further difficulties.

> What was interesting to me in this incident was the intense dilemma the engineer was thrown into by the seemingly straightforward problem of an illegal connection. She had to negotiate a labyrinth of plots constituted by rumours, illicit acts and transgressive collaborations in order to enact or exert her own agendas of personal survival, responsibility to her workers and colleagues, and a wider official accountability. She was also caught in the classic bureaucratic conundrum where, as head of the unit, she was also the newest kid on the block with at best a shallow grasp of local geographies and histories of power and collaboration. All these needed to be unravelled in order to act effectively, or at least safely. (Coelho, 2006)

Figure 2: *Urban water connections: some may be illegal. Hyderabad 2009 (Domal, 2010)*

Some 'entrepreneurial' engineers in a government organisation can earn far more than others by manipulating opportunities to their advantage and networking with powerful actors.

> Some assistant engineers make a lot of money … She goes straight to ministers and their PAs by herself and talks to them boldly – she wields a lot of influence! I cannot do that – I don't go anywhere like that without my husband! (Coelho, 2004, p. 237)

From these accounts, we can see how established practices within South Asian government engineering enterprises are remarkably stable, limiting how engineers can respond by adapting their practices. Change comes slowly if at all; for example, the acute water shortages observed by Coelho (2004) recurred in 2019 for the same reasons (Bloomberg, 2021).

Language and the need for constant supervision

Language is a significant issue that magnifies uncertainties, opening large spaces for alternative interpretations. Many engineers in South Asia speak in three or more languages interchangeably: English; the national language (Hindi, Urdu, Bengali, Sinhalese, Nepalese, etc.); their mother tongue (Punjabi, Sindhi, Marathi, Telugu, Malayalam, Bengali, Tamil, Gujrati, etc.); and possibly local dialects as well, jumping from one to another seemingly at random, referred to as 'code-switching' by linguists. An English technical term may have no local equivalent, and while the meaning is familiar for engineers, for others it can temporarily block comprehension as they figure out which language the word might be, resulting in several seconds of missed conversation. In a context where seniority or high social status demands unconditional respect, automatically accorded to engineers in most workplaces, others will be hesitant to ask clarifying questions as that might imply they were not listening in the first instance. Most people lose concentration after a few minutes of uninterrupted speech: code-switching magnifies gaps, uncertainties and misunderstandings (as well as making interview and field note transcription a far more demanding task for a researcher!) (Domal, 2010).

Engineers' directions often reach factory or site workers through multiple verbal translations. Most South Asian engineers are not fluent in local worker dialects, so their instructions will be relayed through supervisors who translate from a mixture of English, Hindi and possibly the regional language to the workers' dialect(s). Any uncertainty in the minds of workers, therefore, results in at least hesitation and clarification with other workers, and mostly pausing the work until a supervisor or engineer provides explicit instructions, relieving the worker of any potential blame for misunderstandings. Expensive machinery stands idle in the meantime. For workers, mistakes can cost their jobs, particularly if they have minimal employment security. Mistakes can ruin expensive materials or machines, so workers may calculate that the consequences of inaction in the presence of any uncertainty are less severe.

From an external viewpoint, workers who work slowly or cease productive work completely in the absence of a supervisor can appear to be lazy or stupid. Yet, from the worker's viewpoint, this could be seen as a rational decision based on their expectations about consequences and the lack of social security.

Even locals can confuse this rational response as laziness or 'lack of attitude' (Domal, 2010). A similar observation from Nigeria (Kusimo & Sheppard, 2019) may reflect the same reasoning by workers faced with ambiguity and reluctance to act without instructions from someone in authority. The consequence for engineers is the continuous need for vigilant supervision.

The need for constant, highly paid supervision where one engineer or foreman supervises as few as three or four unskilled day labourers adds considerable indirect costs (Trevelyan, 2014) that can be many times the salary cost of the worker. Well-intentioned labour market regulations can magnify the need for supervision. In parts of India, for example, day labour can be hired for a maximum continuous period of only six months. So just as engineers have managed to train labourers to reasonable proficiency, they have to start all over again with new labourers (Domal, 2010). Typically, permanent workers have to be paid at much higher rates and benefits.

Lower education standards in South Asia also increase the need for supervision. Technical workers may be unable or unwilling to interpret drawings or written instructions. Therefore, engineers have to be much more vigilant (Domal, 2010) than in Australia to ensure due care and diligence with technical work. In South Asia, the span of control, the number of technical workers who can be supervised by one person, is usually considerably less than in corresponding enterprises in Australia.

Supervising production and maintenance work takes engineers away from their desks for extended periods, making coordination with other engineers and outsiders more difficult and frustrating (Domal, 2010). Mobile phones have helped in some respects, making access to engineers easier, although handling up to 200 calls daily itself is a significant demand on engineers' time (Domal, 2010). It is harder for engineers, therefore, to engage with formal email correspondence and documentation activity than in a more formally organised firm in Australia. Even at an export-competitive factory much of the production supervision work was being performed by relatively inexperienced engineers (Domal, 2010) who lacked the skills that experienced, specialised production supervisors acquire in countries with longer experience of industrialisation (Mason, 2000).

Activities related to supervision such as technical coordination (Trevelyan, 2007) may require frequent follow-up phone calls to keep priority work front-of-mind in an environment with frequent social distractions and other urgent priorities, including domestic matters and fatigue from long commutes, and often a second job to supplement income.

Financial awareness

Unfortunately, indirect labour costs arising from the need for training and supervision seem to be largely invisible to engineers, even many business owners. Arguments about labour costs, whether of engineers or shop floor workers, are usually based only on the hourly salary costs. Therefore, decisions can drift in directions that magnify overall costs rather than reducing them. The expert engineers took a different perspective, recognising the total cost, including training, supervision, machine utilisation, and all the other indirect costs required to achieve a given outcome, where low productivity more than offsets the low apparent hourly cost of labour.

Here is an engineer, also a business owner, being asked about investing in more automation:

> For any product I think labour cost accounts 7 to 9% and I think in those terms. Even if an increase in the labour cost by 20 percent, the total cost will go up from 1 to 2%, that's all. Why should I think too much about it? (Domal, 2010, p. 159)

This participant missed the connection between labour cost and plant utilisation. While the direct labour cost was only 7 to 9%, indirect costs such as opportunity costs from machinery breakdowns were not considered relevant.

My first-hand business experiences in South Asian firms revealed some of the reasons why few engineers have access to detailed financial information that could alert them to indirect costs. Anecdotal evidence from conversations with other business owners reveals that many keep multiple sets of accounts. The tax inspector will see accounts that show minimal if any taxable income. Another set of accounts is needed to persuade the bank that there are sufficient profits to qualify for a loan extension. The shareholders receive accounts that explain why their dividend increase has to be deferred for another year. The owner's working accounts will report his cash position, but few owners appear to account for asset depreciation.

The business owner has to keep all these accounts confidential to prevent other stakeholders from discovering the extent of deceptions. Anecdotal evidence suggests that some tax inspectors, well-educated but with low government salaries compared to the business owner's income, know they are being deceived and negotiate with the business owner to share the benefits from reducing the firm's apparent tax liabilities. Tax inspectors know it is difficult for a business owner to subsequently regularise their tax position without incurring substantial penalties. A banker explained to me that they know that their commercial loans will perform worse than forecast if the business owner does not allow for depreciation. However, at the same time, they know they will lose profitable business customers to other banks who do not insist on allowing for depreciation.

A research interview with a Pakistani engineer responsible for a US$ 250 million process plant revealed that he was unaware of the requirement to take depreciation into account to calculate profitability. The business owner of a semi-government commercial enterprise limited his spending authority to about USD 200. He explained, referring to powerful local stakeholders: ‘I have to pay bribes out of my own pocket just to get my trucks carrying product to customers past their roadblocks’ (interview by author).

The perceived need by business owners to keep accounts confidential makes it hard for engineers to appreciate financial issues in firms and organisations. Few of the engineers interviewed had any financial responsibilities, significant financial awareness, or authority. In contrast, the few expert engineers had figured out the financial situation of their firms for themselves. However, they still had little or no spending authority delegated to them. It is not uncommon for owners of large South Asian businesses to personally sign and authorise every single payment.

In Australia, most of the engineer participants had significant financial as well as technical accountabilities. While they were not necessarily aware of the day-to-day financial position of their firms, they were required to make recommendations based on financial arguments with significant consequences (Domal, 2010). Most Australian participants appreciated the opportunity costs of equipment failures. At the same time, they had limited appreciation of indirect labour costs, but because direct salaries in Australia are much higher, indirect labour costs are less significant than in South Asia. While Australian engineers are aware of low hourly labour costs in countries such as India and Pakistan, most are unaware of the high indirect costs and low worker productivity.

Formal procedures, information systems

Well-established engineering organisations in wealthier countries like Australia use formalised procedures to help ensure that distributed knowledge reaches people who need it. For example, in a company where the hourly rate for the services of a systems engineer was around three times higher than for small, informally organised firms, this engineer explained how formalised processes help:

> We have very formalised document review systems. For the critical design phases we have actual site meetings and we have checklists of what has to be done at those meetings. We have found that they are very effective. In this project we have probably gone further than just about anyone else has in the world in terms of formalising what previously has been a very informal process. We have checklists for all the major meetings, we have a formal checklist for document review, we have templates for all the major documents, so I think we are very structured in that regard. The client has to check all our conceptual design documents (*i*nterview by author).

He also explained that many clients are reluctant to engage in detailed document checking, but his firm delays project commencement until this has been done. Contrast this with the following field observation at a South Asian engineering consultancy:

> The firm's principal explained their frustration at being unable to win engineering contracts on projects conducted by major international companies and multilateral agencies. 'We have so much local knowledge that they lack. We see them making elementary mistakes just because of that. And we cost far less than their foreign engineers.' Later, while visiting the firm's design office, I saw some large format drawings rolled up on a table and asked if I could inspect some of them. One of the drawings was marked up for a drafter to make changes. I asked about the reasons for the changes. The principal asked one of the drafters to find the documentation detailing the changes. 'Ah sir, only Mohamed would know that, and he is on leave today (author's field notes).

Instead of a formalised system allowing engineers to retrieve information detailing change proposals and approvals, even this large firm had to rely on informal knowledge among its staff instead. Withholding information can also be an apparently rational strategy for workers concerned for their job security or status. We have also seen this phenomenon among maintenance workers in Australia who are reluctant to provide more than the minimum information when interacting with information systems to enter completion reports on their work orders (Gouws, 2014).

Another South Asian engineer at a major process plant explained that there were no formal procedures other than for purchasing: 'I don't have fixed procedures ... each person in this position will institute different procedures to suit himself ... (he) will design the procedures to suit the requirements as he sees fit' (interview with author)

The lack of formality and reliance on memory was also apparent in inventory management practices. At smaller South Asian engineering enterprises, different steel materials awaiting machining lie on the ground with no identification marks. At a major export-competitive factory, inventory management relied on pencilled notes marked on paper records. Unmarked boxes of components were scattered seemingly randomly, awaiting attention from the storeman to be placed in their correct locations. On the factory floor:

> The floor has large potholes and makes it hard to manoeuvre materials handling equipment. It is difficult to read documents and product labels due to inadequate lighting. Inventory is exposed to dirt, water damage, and theft. There is poor housekeeping, often allowing parts to be placed anywhere on the floor, under tables, and behind machinery, making it difficult to

> determine what is supposed to be there and what has been mistakenly placed there (lost). (Domal, 2010, p. 84)

As in the case of the consultancy, critical information relied on fallible human memory. Hourly rates charged to clients for engineers' services, like salaries, reflect value generation. Strong evidence emerged from interviews across firms and countries that formalised information sharing systems and procedures were associated with firms that charged clients significantly higher rates for their engineers. At the same time, especially among younger engineers in Australia, considerable resistance and resentment of these systems was apparent. As one young engineer remarked, cynically: 'Welcome to the firm of 10,000 standard procedures!' (interview with author).

Respect for authority

In South Asia, status is largely ascribed rather than earned through achievement (Trompenaars & Hampden-Turner, 2021), in contrast to a country like Australia, where status arises more from known achievements. Age, seniority, the family name and connections made known during informal conversation, the tone of voice, the use of language, clothing, and even pale skin colour can all convey status and authority, in addition to one's formal position within the firm's hierarchy. Many decades after the end of British colonial rule, white people are still accorded higher respect than locals and are assumed, often incorrectly, to be more honest.

Addressing 'seniors' by their first name is unusual in South Asia, as is speaking out of turn or even at all without being prompted. One avoids raising an issue or asking questions that might expose weakness in one's seniors' thinking or that might conflict with their espoused position. It can be awkward to ask clarifying questions that might expose gaps in one's own listening, memory or comprehension[4] because that might imply failure on the part of one's senior to provide a full and complete explanation. It makes it difficult and possibly risky for subordinates to raise performance difficulties resulting from seniors' earlier directions (Domal, 2010).

However, informal technical coordination activity that underpins the social network enacting distributed expertise in an engineering enterprise relies on being able to work outside

[4] Comprehension gaps arise frequently because of language issues as explained earlier.

lines of authority, whether formal or by attribution (Trevelyan, 2010b), as a construction engineer explained:

> Now, of course officially, there is a line of authority. The engineer can take work to his head engineer who can pass the work to the head draftsman who can direct the drafties what to do. But you don't want to rely on that because it involves too many people and it's too slow. It's quite unwieldy and that's why horizontal interactions are essential. (Trevelyan, 2007, p. 194)

This can be much more difficult in South Asia, as noted by Domal, where authority demands respect. For example, even a minor maintenance problem may require formal approval by a manager to issue spare parts. (Domal, 2010).

South Asian engineers have to work within narrow limits of authority set by their managers and supervisors. Here a senior engineer describes how this limits opportunities for delegation:

> We started a new idea in our assembly plant called a cellular manufacturing system. We organised small cells and the participants were from all levels of the company including executives from different departments like maintenance. [And did it work out?] No, it didn't last long. [Why not?] Because I would say that here the culture is such that people do not like change so they were not receptive to it, and secondly not all departments were involved in it that you needed to execute a job. For example, if there was a problem and the maintenance department had to fix it they would say, 'Okay we have indented the parts and when we get them you would have the thing fixed.' Of course, the indent would have to be processed through the administration department and they would take their own time. Of course, if the cell had been given both responsibility and authority, it would have worked but the authority was not given to them, only the responsibility. That's why it did not work (interview by author).

Informal authority in wealthier countries such as Australia relies more on a visible commitment to general organisational goals (Zussman, 1985), so it is possible for engineers to exert influence informally, outside lines of formal authority, as this engineer explained.

> Now if you work through the traditional lines of authority it's going to take too much time and may even get forgotten. To do this effectively the subcontractor engineer has to develop a relationship with the client engineer and create an understanding in the client engineer that if he signs off on something that turns out to be incorrect then the problem is going to come back to bite him in the end. This kind of situation illustrates why an engineer spends a lot of his time managing up, managing sideways and managing down all at the same time … you need lots of subtle negotiation. Resorting to authority is a total waste of time as it only creates resistance and the lines of authority may not even exist (interview by author).

Within certain limits, and with significant effort, it is possible to change this cultural practice in a South Asian enterprise, as this expert engineer explained:

> It is a one-person company – Ashitosh, he is the expert on everything, even in areas he hasn't a clue about. That in itself is very self-restricting.… You have to provide an enabling environment for people to grow.… You can't have an island of excellence in a sea of mediocrity, you just can't. You know the guys who have gone out from my department, even to marketing, they are doing very, very well. They are the only guys who can stand up to Ashitosh and say, 'No sir, we are going to do it this way, not the way you are saying.' And they can say that. That in itself is an achievement. I'm the only guy here in this firm who calls the chief executive by his first name. Everyone else calls him 'Sir' or 'Sahib' *(interview by author)*.

This engineer, over time, had cultivated a different culture within his product development group, one that encouraged subordinates to ask questions, to raise their own ideas and to subject accepted ideas to analysis and testing by experiments. In making these changes in cultural practices, along with other practices such as inculcating an awareness of the economic implications of engineering work, this engineer had enabled such significant value generation that his firm could compete with imported products (Trevelyan, 2022). Over three decades, this engineer had learned how to create a productive engineering enterprise within the firm. Along with other expert engineers with similar achievements, this shows that it is possible to overcome environmental factors in South Asia, though not without significant effort.

Exposure to sales engineers

Sales engineers perform an influential role in countries like Australia by providing workplace education for engineers about new products, technologies and services that can increase the performance of firms.

Specialist suppliers of engineering products and services, firms that almost always sell their products to other engineers, employ sales engineers to perform marketing functions for the firm. A sales engineer identifies a potential customer and interprets the customer's needs in terms of technical solutions enabled by the specialised products and services offered by the firm. The sales engineer may perform significant technical analysis, create designs incorporating the firm's products, and promote this work in terms of a value proposition for the customer. For example, a firm selling precision linear bearings and servo motors may create a design for a precision positioning table for a firm employing engineers who have limited experience of their own with this technology. The sales engineer anticipates (or hopes) that the customer engineer will be able to persuade his enterprise to issue a purchase order for specialised products supplied by his firm. A sales engineer knows that a significant part of the work is to educate customer engineers about the capabilities of the products supplied by their firm, and also to build a relationship that will persist over time. Sales engineers also participate in trade shows to extend their networks of potential customers (Darr, 2000, 2002).

Engineers in South Asia have less exposure to sales engineers and the education they provide, partly because the specialist engineering supply firms perceive fewer business opportunities, and partly because of the immense number of engineering enterprises in the major South Asian countries. Another factor deterring many specialised suppliers is the tendency of purchasing departments in South Asian firms to prioritise price in their purchase decisions. It takes special knowledge and experience developed by a very small number of engineers to overcome this tendency, as explained earlier in this paper.

Conclusions

The paper presents evidence that there are significant differences between engineering practices in South Asia and Australia. Very little research has been conducted in other countries in the Global South: the evidence we have suggests similar differences. Naturally, there are large practice difference between different firms and government engineering enterprises as well: this paper focuses attention on similar practices observed in several different enterprises. This result raises questions about the validity of an implicit assumption in instruments, such as the Washington Accord, that professional engineering practices are similar worldwide and there is no need to address significant regional variations.

The paper identifies engineering salaries (across a broad range of disciplines) and the cost of engineered goods of equivalent design, performance, quality, reliability and durability as two potentially objective measures of engineering performances. Compared with Australia, South Asian salaries are much lower and the costs of most engineered goods are significantly higher, with some notable exceptions.

Evidence presented in this paper helps to explain the reasons for these differences. There are environmental factors that cannot be changed such as geography, climate, economic environment, labour market, levels of trust in strangers, languages spoken by engineers and others, availability of social welfare, governance and legal systems, access to education, and literacy. There are also factors that can be changed, such as practices showing respect for authority, access to education resources on products and services provided by specialist suppliers, organisational procedures, and financial awareness, particularly of indirect labour costs and machinery downtime opportunity costs.

Limitations

Given the limitations of a journal paper, it is not possible to describe all the factors observed: the paper focuses on factors that seemed more significant. For example, the lack of reliable materials testing laboratories in many parts of South Asia also imposes significant limitations on engineering performances. There were insufficient female participants to draw any findings related to gender. While there may be some similarities in other countries in the Global South, further research is needed before the results can be confidently generalised beyond South Asia. Also, given large variations in practices between different firms and enterprises, it would be unwise to generalise the findings across all enterprises in a particular country or region.

Suggestions for engineering educators

Each of the factors influencing engineering practices described in the preceding sections points to spaces that are seldom addressed in professional engineering education, if at all. Nevertheless, if we are to give our students (and their parents) the best chance to fulfil their dreams to become successful professional engineers in their home countries, education programmes must prepare them to become competent novices in local engineering enterprises.

As explained earlier, research points to socio-technical interactions with other people as being the most critical location-dependent aspects of engineering practice. However, even a casual examination of a typical engineering undergraduate curriculum will reveal hardly any formal instruction devoted to socio-technical aspects of engineering practice. Even courses such as 'project management' usually focus on documents and planning methods and avoid scholarly discussions on human behaviour.

However, education, particularly in engineering, results from socio-technical interactions between faculty, teachers, students, families and part-time employers. Once education is seen as a site where socio-technical interactions between people form the dominant activity, it enables faculty to draw students' attention to the significance of socio-technical interactions in engineering practice and the cultural factors that shape those interactions. Educating professional engineers to be effective teachers could help improve practice because a major part of engineers' daily interactions with others is remarkably similar to collaborative learning in classrooms (Jonassen et al., 2006; Trevelyan, 2010b). With appropriate knowledge of the socio-technical contexts in which engineering is practised locally, faculty can provide students with contextual knowledge so students can learn how universally applicable technical knowledge is actually used in practice. While it is preferable for faculty to have first-hand exposure to practice to acquire contextual knowledge, another way to do this is to arrange for students to observe engineers nearby and write about their observations (e.g., Anderson et al., 2010).

There are several measures that faculty could implement without significant curriculum changes.

1. Perhaps the most important research finding is that engineers in South Asia who learn to generate sufficient commercial value can (eventually) earn salaries least as high as engineers would earn in Australia. Faculty can explain to students that there is no need to migrate to a wealthy country to gain a high salary and income security. However, graduates will need to learn how to work with local people to deliver results in line with expectations.
2. Students who learn that socio-technical interactions will take most of their time will be less likely to experience a mismatch between expectations and the reality of engineering work as engineers. Students can also learn that these interactions are important for their own success. Trevelyan (2020) provides guidance to help students rapidly acquire socio-technical workplace skills.
3. Collaborative learning methods are not only among the most effective classroom techniques, but can also provide a setting in which students can appreciate the significance of socio-technical interactions (Smith, Stirling & Berkhout, 2005). Solitary technical work drawing on knowledge learned in engineering school may comprise a tiny part of engineering practice, and hands-on work even less.
4. A definition that links engineering with productivity can help students understand the economic and social benefits from engineering activities:

> Engineers are people with specialised technical knowledge who conceive, deliver, operate and sustain artificial objects, systems and processes that enable other people to do more with less effort, time, materials, energy, uncertainty, health risk, and environmental disturbances. (Trevelyan, 2020)

5. Faculty can explain some of the environmental factors listed in this paper that influence productivity and engineering practices. Many people in low-income countries imagine that their countries remain poor because of corruption by elites and economic

mismanagement by incompetent rulers. However, as explained in this paper, there are several other factors that impede economic development. Among these are the factors that make it harder for engineers to provide similar outcomes as in Australia.

6. Faculty can help students understand how social-cultural factors such as trust, the need to maintain support networks, and respect for seniors influence the ways that people interact with each other, and how this can influence technical decision-making. For example, a classroom discussion on how to work with a professor who has made a significant mistake in his technical analysis might be helpful for students to appreciate the influence of the social hierarchy.
7. Faculty can help students learn that, as a result of these factors influencing engineering practice, the cost of engineering activity in the Global South is often higher than in countries like Australia, for similar product design, performance, quality, reliability and durability. This will seem counter-intuitive for many, even most faculty. Data on the cost of safe drinking water provided in this paper, easily verified, can help students understand this. The higher costs result from lower productivity. This is also an opportunity: engineers who can reduce costs to levels comparable with wealthy countries will be well rewarded by their firms.
8. Faculty can help students understand the significance of indirect labour costs such as supervision.
9. As noted above, faculty can encourage students to observe practising engineers and interview them to observe socio-technical interactions in practice (e.g., Anderson et al., 2010).
10. Faculty can encourage students to participate in extracurricular activities, particularly part-time work, and reflect on the social interactions that they experience to help them become more observant of human behaviour. Students working as volunteers can learn collaboration and coordination techniques that they will apply in engineering workplaces. Service learning has been shown to facilitate student learning in the USA and has now begun to be implemented in some Indian engineering schools (Dustker, Bandi & Oakes, 2021).

One cannot be sure that improving engineering education will influence what happens in engineering workplaces where organisational culture can overwhelm earlier behavioural influences (Buch, 2016). However, the observations and suggestions in this paper may help engineering faculty staff in the Global South to help prepare a greater proportion of their students for competent practice as engineering novices in local workplaces in their own countries, and not just in Australia, the USA and other wealthy countries.

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