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Empirical Research Paper

Educating engineers of the future: T-shaped professionals for managing infrastructure projects

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ABSTRACT

Infrastructure projects are costly, colossal, complex, captivating, controversial, and laden with control issues. The development of these projects causes environmental, social, and political disruptions in the local environment, which have to be carefully handled by professionals in the field. This article aims to enhance the performance of infrastructure development professionals by highlighting the necessary competencies and how these competencies can be improved through preparation and training. After discussing the different shapes of professionals, the competencies for infrastructure development are discussed. It is argued that the competencies for infrastructure development are similar to the T-shaped framework. Competencies such as in-depth knowledge, ability to understand and work in different areas, being flexible and adaptive to change, having decision-making capabilities, and willingness to be life-long learners are instrumental in creating T-shaped professionals for infrastructure development. The different learning activities such as lectures, on-site visits, role plays, case study discussions, problem-solving exercises and project work can be employed to educate professionals in the area. The suitability of these methods for online education is also discussed. The study calls for more research to trace the effectiveness of learning activities in the infrastructure sector.

1. Introduction

Infrastructure projects are costly, colossal, complex, captivating, controversial, and laden with control issues (Frick, 2008). These projects are plagued with two types of complexity – detail complexity and dynamic complexity (Hertogh and Westerveld, 2010). Detail complexity involves the technical challenges associated with infrastructure projects' multiple interrelated physical components. Professionals require in-depth knowledge and expertise to understand these challenges and make decisions. Dynamic complexity focuses on the evolving nature of these projects, where new stakeholders, interactions, and complexities sprout during the project. Additionally, the development of these projects causes environmental, social, and political disruptions in the local environment, which must be carefully handled (Sturup, 2009). Throughout the project's lifecycle, there are multiple internal and external stakeholders with often conflicting demands that must be managed within the resource constraints of the project, at times by adopting new technologies (Xie et al., 2014; Datta et al., 2020). Professionals have to be flexible and adaptive to respond to these dynamic complexities. Thus, infrastructure development is demanding as professionals must simultaneously manage the detail and dynamic complexities.

Professionals in infrastructure projects require multiple skills to solve these diverse challenges and complete the project successfully (Ahmed et al., 2014). In addition to technical skills, professionals should also exhibit specific patterns of behaviour to help them attain the desired outcome (Egbu, 1999). For example, professionals must collaborate and lead multidisciplinary teams, communicate across disciplinary and cultural divides, and become change agents who foster open innovation (Ramazani and Jergeas, 2015; Demirkan and Spohrer, 2015). Independent of their background or expertise, all professionals working in the sector should cooperate with other disciplines to mitigate the challenges associated with infrastructure development. In addition, more competencies are required to manage projects in the modern digital world (Algeo et al., 2021). Rather than being a technocrat with in-depth knowledge in one area, or a generalist with a bit of knowledge of everything, we argue that infrastructure project professionals must have a T-shaped competency profile to tackle the challenges. T-shaped professionals have a basic understanding of adjacent disciplines and an in-depth knowledge of one discipline. For example, Sharp et al. (2011)

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note a convergence of multiple disciplines in developing the chip for treating Circulating Tumor Cells (CTCs). The physicists calculated the optimal blood flow, engineers constructed the microposts, biologists attached the appropriate antibodies to the microposts, and clinicians tested the chip under real-world conditions. Similarly, this article aims to enhance the performance of infrastructure project professionals by highlighting the necessary T-shaped competencies and how these competencies can be improved through preparation and training. Specifically, we ask (1) what are the T-shaped competencies required for infrastructure development, and (2) how can we develop these T-shaped competencies?

In the next section, the different shapes of professionals are reviewed, following which the unique position of T-shaped professionals is discussed. Subsequently, the various competencies required for infrastructure development are anchored in the T-shaped professionals' framework. Then, the curricular and pedagogical strategies, i.e., the types of learning and activities for education, for creating T-shaped competencies for infrastructure development are discussed along with how they operate in online education. Finally, the conclusion section summarizes the key insights of the article, highlighting the limitations and scope for future research.

2. Different shapes of professionals

Professionals can have in-depth knowledge in one or more areas or general knowledge in multiple areas. Depending on their competency, professionals can be categorized into different shape profiles. In literature, all kinds of shapes are discussed: for instance, I-shaped, dash-shaped, H-shaped, comb-shaped, and T-shaped. Demirkan and Spohrer (2015) noted that these shapes can be considered a metaphor for a professional's range of knowledge, skills and competencies.

I-shaped professionals have in-depth knowledge in one area. They have undergone narrow but in-depth training in their specialization and can be considered experts (Bierema, 2019). Professionals can be updated with the latest knowledge in their discipline as their profile is mono-disciplinary (Uhlenbrook and Jong, 2012). Researchers have argued that the current education system focuses on creating such experts who are siloed into their functional discipline (Demirkan and Spohrer, 2018). However, modern-day challenges require the ability to span and cooperate across disciplines (Bierema, 2019). Dash-shaped professionals are horizontal experts with highly functional collaborative and boundary-spanning skills. They lack expertise in one discipline and can be considered as 'a jack of all trades, a master of none' (Bierema, 2019). They are generalists with a good breadth of knowledge across many areas but do not have deep specialty knowledge (Uhlenbrook and Jong, 2012). Even though dash-shaped professionals have some knowledge about everything, Babatope (2020) argue that they add very little value to a team as they do not have in-depth knowledge in any area. H-shaped professionals (also called Pi-shaped professionals) have in-depth knowledge of two disciplines. They are professionally 'bilingual' as they can synthesize the two professions for others (Tranquillo, 2017). These professionals are up to date with the trend in both areas; however, they cannot expand to other areas as they are limited by their ability to learn new areas and adapt to the changing requirements of the industry (Piciocchi et al., 2017). Comb-shaped professionals or M-shaped professionals have varying levels of expertise in multiple disciplines. In contrast to H-shape, they know more than two disciplines; however, that knowledge may not be as in-depth as H-shape. Additionally, their breadth of knowledge is not broad, flexible, and open-ended compared to dash-shaped professionals (Uhlenbrook and Jong, 2012).

T-shaped professionals are uniquely placed as a combination of I-shaped and dash-shaped professionals combining their advantages and mitigating their disadvantages. Unlike I-shaped professionals, they are apt to solve modern-day problems with their broad and open-ended knowledge of multiple areas. They add value to a team with their in-depth knowledge in one area of expertise compared to dash-shaped professionals (Babatope, 2020). Thus, T-shaped professionals have in-depth knowledge of one discipline and high boundary-spanning capacity levels (Bierema, 2019). The depth and breadth of competencies for I-shaped, dash-shaped, H-shaped, comb-shaped, and T-shaped professionals are depicted in Fig. 1.

T-shaped professionals include the advantages of I-shaped and dash-shaped professionals and are more suitable to solve modern-day challenges, such as infrastructure development. Traditional university courses seek to educate students as I-shaped professionals who are experts in one area of specialization; however, organizations demand T-shaped professionals uniquely equipped to work in an interdisciplinary or transdisciplinary fashion.

3. T-shaped professionals

The term T-shaped professionals first emerged in the consulting world with a 1991 London newspaper editorial by David Guest. He highlighted that T-shaped professionals are a razor that can cut through all the complexity in the increasingly complex world. The term caught up in the academic world with the 'Harvard Business Review' article by Hansen and von Oetinger (2001). They highlight that these professionals are uniquely skilled in solving problems and managing change by working deliberately across the boundaries of functional or organizational units. While remaining committed to an individual business unit, i.e., the vertical part of 'T,' these professionals break through the traditional corporate hierarchy to share knowledge freely across the organization, i.e., the horizontal part of 'T.' Thus, T-shaped professionals are specialists able to translate themselves into other disciplines and simultaneously translate the interests, objectives, and concerns of other constituencies into their own (McIntosh and Taylor, 2013).

T-shaped professionals have in-depth knowledge in one area. This expert knowledge can help them be deep problem solvers in their home discipline. However, deep knowledge alone is insufficient in constantly changing global contexts with exponentially increasing knowledge, growing market competition, advancing technology, and intensifying political volatility (Bierema, 2019). In this context, the ability of T-shaped professionals to interact with and understand specialists from a wide range of disciplines and functional areas comes into use. Such an ability helps them blend other competencies such as business acumen, technical skills, interpersonal skills, cultural insight, etc. Their expertise makes them valuable collaborators and problem solvers (Harris, 2009). The ability of these professionals to understand and traverse multiple disciplines allows them to consider the challenges of other fields and become decision-makers and leaders in their sector (Barile et al., 2015).

Along with in-depth knowledge in one area, T-shaped professionals have multi- and interdisciplinary thinking depicted in the broadened top bar of the T-shape (Kamp, 2016). These professionals are also empathetic, willing to branch out into other skills to find a solution rather than claiming that the problem cannot be solved (Bierema, 2019). Their horizontal breadth and flexibility translate into boundary-spanning skills and attitudes that allow enhanced adaptive and innovation capacity (Demirkan and Spohrer, 2015). The vast experience of these professionals in different areas enables them to adapt quickly to other areas. They are swift to adapt to role changes and are fit to work in multidisciplinary, multifunctional, or multicultural contexts. This flexibility enables them to work collaboratively with a team and simultaneously have empathy for customer engagement.

T-shaped professionals are also lifelong learners with open minds who collaborate easily across their local and global networks (Demirkan and Spohrer, 2015). They are entrepreneurially minded challenge seekers who engage actively with other disciplines to understand and appreciate their norms, theories, approaches and breakthroughs to create opportunities (Brown et al., 2015). Thus, they can face various wicked problems, such as climate change, world hunger, war, political deadlock, etc., that do not have readily apparent solutions (Barile et al., 2015). The different competencies of a T-shape professional are depicted

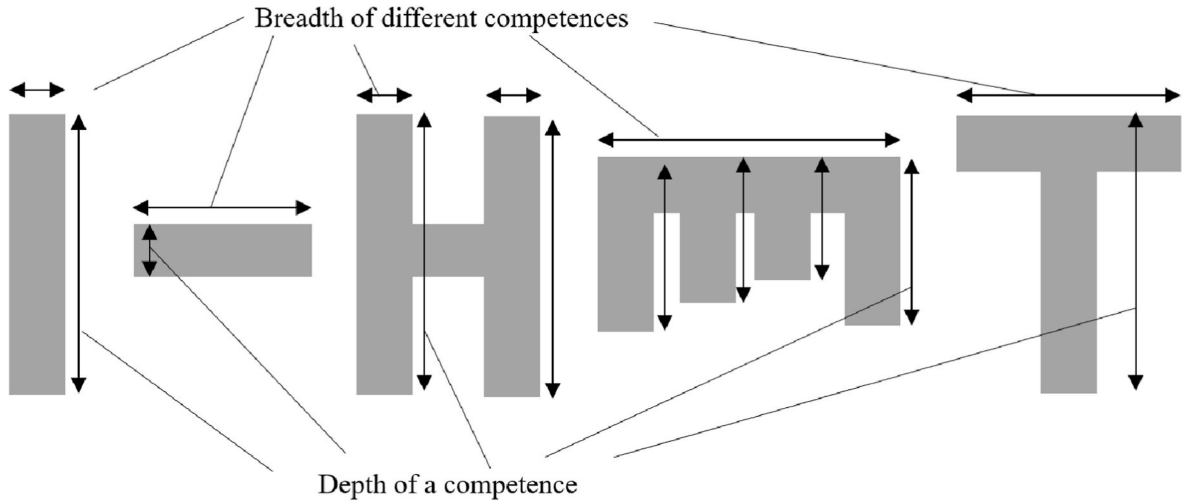

Fig. 1. I-shaped, dash-shaped, H-shaped, comb-shaped and T-shaped professionals.

in Fig. 2.

Together with the direct competencies of in-depth knowledge and the ability to understand different disciplines, T-shaped professionals have indirect competencies such as being flexible, empathetic, adaptive to change, and willing to be life-long learners.

4. Competencies for infrastructure projects

Professionals working on infrastructure projects have multiple roles, such as governance, leadership, liaison, monitoring, disseminator, entrepreneur, disturbance handling, resource allocation, and negotiator (Pilkienė et al., 2018). Filling in these roles requires a mix of technical and managerial competencies. The most notable framework for competencies in infrastructure development is the Project Management Institute's competence triangle (Project Management Institute, 2017). They highlight that project managers must be technically competent with domain knowledge, leadership competent with the ability to communicate and maintain relationships, and strategically competent to think holistically about the project system. Remington (2011) has argued that project managers should also understand the complexity of systems, deal with cultural misunderstandings, and exercise political skills. We review some of the competencies for infrastructure

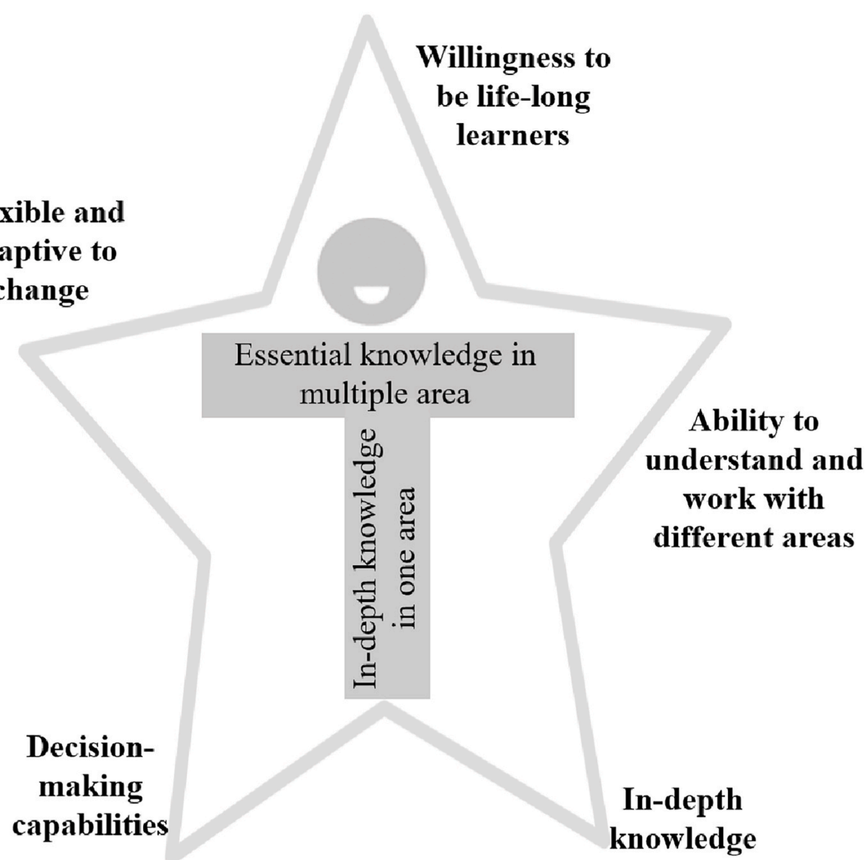

Fig. 2. Different competencies of T-shape professionals.

development from the literature.

First, professionals need to have in-depth technical knowledge. Technical knowledge involves understanding technology, construction methods, and allied areas (Nuwan et al., 2020). These include a sufficient understanding of health and safety regulations, quality control, and building codes and regulations (Ahmed et al., 2014). They should have adequate knowledge for interpreting contracts, drawings, and other construction documents, identifying project activities and their relationships, listening ability and paying attention to details (Bhattacharjee et al., 2013). They should also have the legal knowledge to understand legal concepts related to the industry, such as claims and litigation (Simmons et al., 2020). In-depth knowledge can also be for areas such as project management, negotiation, resource management, stakeholder management, dispute management, or innovation processes (Dogbegah et al., 2011). In the modern era, digital competencies are required to deal with the fundamental change in how we live, work and relate to one another (Marnewick and Marnewick, 2021; Ninan et al., 2022; Algeo et al., 2021).

Professionals should also be able to bring people from different disciplines and cultural backgrounds to solve complex problems (Simoni and Schwank, 2021). For example, Hansen and Von Oetinger (2001) record how site visits, peer assistance and advice from professionals working on technical, legal, tax, safety, accounting, and financial issues were instrumental in delivering a construction project in China on time and under budget. Smits (2013) studies the internal dynamics between project participants during the cross-cultural collaboration in the Panama Canal Expansion program and highlights practices such as seeking consent, storytelling, crafting reciprocal relationships, and synergizing to improve collaboration. Shared ideation generally creates more effective solutions than working in silos (Simmons et al., 2020). Professionals seek the best combination of individuals to build an effective team based on knowledge, skills and personality characteristics to build human capital (Sankaran et al., 2020). They should be able to maximize human relationships and get the most out of every team member (Simmons et al., 2020). While bringing people together, they need to understand the 'big picture,' i.e., how the whole system works together and recognize the impact of different system elements on the whole (Simmons et al., 2020). The big picture is generally the economic, political, and social goal of the project as it impacts the organization's mission and performance. Hertogh (2013) noted that a team of T-shaped professionals requires far less management intervention to work together as they can understand and work naturally with different disciplines.

Another competency required for infrastructure development professionals is thinking critically, challenging the status quo, and being adaptable to change (Van Vliet et al., 2005). They must respond to daily tasks, especially adversity or unexpected events, which are frequent in unique and temporary organizing, with clear analysis, good decision-making, and successful improvement (Simmons et al., 2020). Jaafari (2003) recommends that professionals be more reflexive in managing complexity and change in construction projects. They should be responsible to society and be adept at dealing with stakeholder needs in the public sphere and private businesses (Maak and Pless, 2006). They must perform duties in good faith while maintaining the best interests of all parties involved and understanding the impact of their actions on others (Simmons et al., 2020). Professionals must understand other stakeholders and exhibit environmental and practical awareness (Arditi et al., 2013). Thus, professionals must demonstrate emotional maturity while working in the infrastructure development sector (Zuo et al., 2018).

Professionals must also have decision-making capabilities and leadership skills to manage infrastructure projects (Ahn et al., 2012). They should be able to make complex decisions (Zuo et al., 2018) and assert their opinion in a firm but professional and nonaggressive way (Simmons et al., 2020). They also need to cultivate a vision, which can create a sense of unity and help navigate the project during difficult periods (Drouin and Müller, 2021). Thus, professionals' leadership competency helps them motivate employees to improve, achieve more and grow in the organization (Simmons et al., 2020). To create a vision and assert their opinion non-aggressively, professionals need to have communication and report-writing skills (Attakora-Amaniampong, 2016), such as using the proper labels to bring people together (Ninan and Sergeeva, 2021). English language skills are also required to enable coordination and deliver infrastructure development in the current global market (Nuwan et al., 2020).

Along with maintaining in-depth knowledge in their area of specialization, construction professionals should also be willing to learn, expand their knowledge base in multiple disciplines, and evolve horizontally (Briscoe et al., 2001). Project managers must develop from being a 'trained technician' competent in a specialization to a 'reflective practitioner' able to learn multiple areas (Schön, 1983). The learning is not always planned and often is obtained by surprise with the opportunity and the people around, shaping the professional's lives during and after the project (Sergeeva and Davies, 2021). Few professionals take time to recollect their experiences and talk to young engineers to transfer their knowledge (Freeder et al., 2021). Professionals must also apply their skills and resources to new contexts, thus adapting to changing environments (Bhattacharjee et al., 2013). In addition to this, infrastructure development is an ever-growing field with different technologies such as the internet of things (IoT), Artificial intelligence (AI), and Machine Learning (ML) being used to make the beneficiaries' life easier. These professionals must be transdisciplinary, integrating different disciplines to arrive at a transcendent understanding or solution that moves beyond traditional disciplinary boundaries (Choi and Pak, 2006).

The different competencies for managing infrastructure projects are comparable to the T-shaped competencies, as shown in Table 1. For infrastructure development, in-depth technical knowledge of legal matters, safety, and allied areas. Professionals must also understand and work with different disciplines to solve complex problems. They must also be flexible and adaptive to change and exhibit emotional maturity while dealing with people and the environment. They should be competent to lead, instil vision and assert their opinion non-aggressively. As the sector is evolving and bringing in new

Table 1
T-shaped competencies for managing infrastructure projects.

Sl. No	T-shaped competencies	Competencies for managing infrastructure projects
1	In-depth knowledge	In-depth knowledge of legal matters, practices and regulations, project management, dispute management, resource management, etc. (Nuwan et al., 2020; Bhattacharjee et al., 2013; Dogbegah et al., 2011)
2	Ability to understand and work with different disciplines	Infrastructure development addresses complex problems, the solution of which will be in multiple disciplines (Hansen and Von Oetinger, 2001; Simmons et al., 2020; Sankaran et al., 2020)
3	Flexible and adaptive to change	Infrastructure projects can bring in new stakeholders throughout their lifecycle necessitating new competencies to address their concerns (Van Vliet et al., 2005; Jaafari, 2003)
4	Decision-making capabilities	Infrastructure projects work as a system with multiple interdependencies, and professionals require leadership and decision-making capabilities (Ahn et al., 2012; Zuo et al., 2018)
5	Willingness to be life-long learners	An infrastructure professional will work on multiple projects and require different competencies to deal with challenges in a particular project. Hence, they have to be life-long learners (Briscoe et al., 2001)

technologies, professionals must also be lifelong learners who can develop horizontally.

It is often not possible for one professional to have in-depth knowledge in all the areas associated with infrastructure development. One T-shape does not fit all, as individuals have different in-depth expertise in one area, i.e., vertical leg, and different combinations of other expertise, i.e., horizontal bar (Uhlenbrook and Jong, 2012). Thus, there need to be multiple T-shaped professionals in infrastructure development with different combinations of expertise. Simmon et al. (2020) note that professionals in the construction industry need to recognize their limitations while addressing complex problems. They should be willing to look to other areas to seek solutions for modern challenges. It is vital to have professionals with different T-shapes with the right mix of expertise to maximize the coherence of human capacity and solve complex problems (Uhlenbrook and Jong, 2012). Hence, multiple T-shaped professionals with specializations in different knowledge areas must come together to deliver infrastructure projects, as shown in Fig. 3.

The number of skills required for an infrastructure project can depend on the project's size, type, and complexity. For example, the number of professionals will increase with the size of the project. Similarly, the skill requirement for constructing a nuclear power station will differ from highway construction. Also, the complexities of the project, such as the need for land acquisition and utility shifting for an urban project, would be different from an underwater tunnel project.

5. Education for infrastructure project management professionals

Education and training in infrastructure project management can benefit the organization as it helps deliver projects cost-effectively to the employees as it helps in appraisals, and for the society at large as it helps to deliver projects more quickly. Education in infrastructure development should foster the development of T-shaped professionals who are prepared to combine specialized knowledge with the flexibility to build high-performing teams that generate innovation. The purpose of higher education must be to educate graduates to keep pace with the changes in the infrastructure development sector (Boffo and Fedeli, 2018). Training here is done within an artificial environment and is implemented before the trainees start to work on the job (Tennant et al., 2000). Students in classroom settings can be trained to be T-shaped professionals with the right set of activities that change their behaviours (Ghosh et al., 2011). Such training has to be a systematic process of instilling the necessary knowledge, skills, and attitudes that enhance the performance of the employees and make them competent to tackle on-field challenges (Sahoo and Mishra, 2018). The purpose of education is to enable different types of learning.

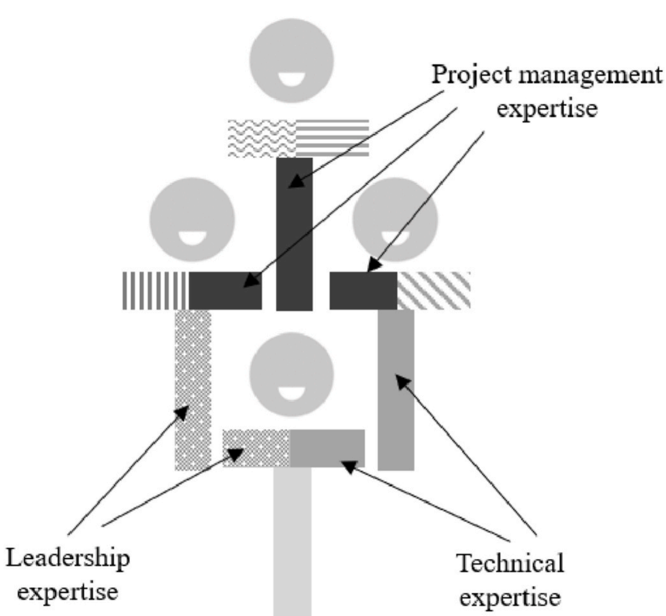

Fig. 3. An example of T-shaped employees with different and varying depths of expertise in managing infrastructure projects.

5.1. Types of learning

Laurillard (2013) describes six types of learning, i.e., acquiring, inquiring, discussing, collaborating, practicing, and producing. Acquiring knowledge is still the most common way of formal education. Learners acquire knowledge when they are listening to the instructors. Other ways to acquire knowledge are reading books, listening to podcasts, or watching demos and videos. The instructor is active in this type of learning, and students are passive. Acquiring knowledge is easier with the advent of digital technologies. Multiple sources are available online, drawing on multimedia capabilities such as pictures, diagrams, animation, audio, video, and hypertext. The type of knowledge transmitted through acquisition is an understanding of what others have discovered, hearing about expert ways of thinking and practicing, and what is known already in their field. Instructors can have a question-and-answer section during and after the lecture to facilitate dialogues and break the one-way flow of information.

Another way of learning is through inquiry. Learning through inquiry adds another dimension to the one-way, teacher-to-student flow of information discussed in the acquiring type of learning. Here, students develop their knowledge by questioning, investigating, analysing, hypothesizing, designing, interpreting, sharing, arguing, and synthesizing the knowledge gained through acquisition. They look for extra information and search for knowledge in books, videos, databanks, libraries, and repositories. In the current digital world, students can seek answers to questions that puzzle them in online sources often available at their fingertips, enabled through the internet. Thus, students are more active in learning through inquiry, take a critical and analytical approach, and exhibit greater ownership of their learning. Here, students have to go beyond class presentations and assigned readings to find new sources of information (Schwartz et al., 1999). Such inquiry-based learning is essential as it cultivates students with the fundamental skills of 'how to seek information,' which is necessary for developing their knowledge of future problems. Inquiry-based learning aims to foster a more active approach so that students develop a richer understanding, personal engagement with the ideas, and a critical stance toward the knowledge (Laurillard, 2013). Students still need guidance and mentoring from the instructor to ask the right questions and seek the right resources to gain knowledge.

Learning through discussion involves discussion with peers in buzz groups, small group sessions, discussion groups, activity groups, tutorials, and seminars. The objective of discussion is to enable a critique of ideas from different students and how such critique leads to the development of a more elaborated understanding of the concept. There can be various forms of discussion: teacher-led or student-led, structured or unstructured, or face-to-face or online. However, learning through discussion does not just happen; it requires careful planning and support by the teacher if students are really to develop their cognitive understanding. Discussion can be applying what has been learned, providing evidence to an argument, critiquing ideas, or even working towards an agreed output (Swann, 2007). The role of the instructor is to design the context for the discussion by providing students with material to analyse, advising them to prepare in advance for discussion, and grading each student's level of participation.

Learning through collaboration is similar to discussion but poses a more formidable challenge as learners have to produce a shared something as the externalized fruit of the negotiated discussion. It involves two or more people attempting to learn something together (Jones and Issroff, 2005). In contrast to inquiry and discussion with peers, in learning through collaboration, the aim is to build knowledge or an idea as a group (Scardamalia and Bereiter, 2006). The output from the collaboration exercise can be a text or diagram, video or model. Rather than the output, the process makes the learning happen. Learning happens through collaboration, as each learner can learn from what others say and how they address the topic. Each learner spends time generating explanations and ideas, and more learning is likely to happen as part of the group than in individual learning. Group work also enables team building as each member must work together and contribute to the group goal. The collaboration process is not simply the exchange of ideas but also debate and dialogue, involving conflict and challenge, support and scaffolding, all to create a shared output. The instructor creates an atmosphere for collaboration by envisioning the lesson, enabling collaboration, encouraging students, ensuring learning and evaluating achievement (Urhahne et al., 2010).

Learning through practicing involves the instructor giving exercises for the students to apply their understanding of the concepts. It invites the learner to adapt their conceptual knowledge to the task at hand and then reflect on what that experience means for their understanding. This type of learning predates any other form of learning as part of the 'learning from experience.' Learning through apprenticeship and learning through imitation can be categorized as learning through practicing. The aim is to enable students to develop an enriched understanding of the knowledge by practicing the skills picked up through acquiring or inquiring. The practicing cycle involves highlighting the goal, practicing action on the part of the student, getting feedback from the instructor, and revising the action by the student. It can include exercises in class or can be outside classroom settings in the form of homework.

Learning through producing involves students' learning while creating essays, reports, designs, artifacts, or models. The student consolidates their learning by acquiring, inquiring, discussing, collaborating and practicing. In the process, students must pull together and organize their exploration, which helps in learning through critiquing and reflecting. Such students' articulation of their current thinking enables the instructor to evaluate the work with feedback, guidance, and further explanation. These different types of learning can be cultivated in students through various learning activities.

5.2. Activities for learning

Different activities and training methods are used in the classroom and online settings for knowledge gain, interpersonal skill development, attitude modification, participant acceptance, and knowledge retention (Kaupins, 2002). These include lectures, on-site visits, case study discussions, role-play, problem-solving exercises, and project work.

Lectures help cultivate the necessary in-depth technical knowledge for students in infrastructure development. Knowledge of legal matters, practices and regulations, project management, dispute management, or resource management can all be taught in classroom settings. Learning happens through acquiring. Questions from the students can be encouraged to make the lectures more interesting and facilitate a two-dimensional interaction. Massive open online courses (MOOC) can help students develop in-depth technical knowledge in the modern digital era (Falcao and Fernandes, 2016). There are multiple project management MOOCs such as the 'Project Management of Engineering Projects: Preparing for Success,' which are offered free of charge.

On-site visits can help students understand how different areas work together in managing infrastructure projects. At the same time, students can be exposed to different contexts and learn construction in the global arena. More prolonged term engagement with the site, in the form of internships and shadowing, can also help students understand how different specializations are required to solve problems. Wang and Zhu (2021) discuss how a megaproject professional considered a senior megaproject professional his mentor and adopted his philosophies in the current project. On-site visits can involve learning through inquiring as students ask questions about the observations while being motivated to read more and investigate these observations. For example, a construction management course at the Indian Institute of Technology Madras (IIT-M) involved a compulsory on-site internship for a minimum of two months during the semester break. The students must produce a report on the critical learning from the site visit, which can be learning through producing. Students can learn from practitioners worldwide in a digital forum in the digital era. Social media platforms such as Facebook and Clubhouse offer informal support, peer-to-peer mentoring, continuous professional development, and knowledge-sharing opportunities for project delivery professionals (Harrin, 2022).

Case studies can expose students to different contexts and experiences in them. From the case, students discuss the reasons for the success or failure of the case. For example, the case study of the High Speed 2 project in the UK was used in a project management course at University College London (UCL). After a brief overview of the case and context, students were given a set of questions to discuss in groups. Following the group discussion and student feedback, the outcome of the case is discussed. Then the class explores why the outcome happened and outlines how to improve performance in future projects. Case study discussions can help cultivate essential decision-making capabilities as students are exposed to different scenarios. Cases also help students understand how other disciplines must be explored to solve complex problems. Professionals must also participate in case study discussions to understand the evolving nature of the management of infrastructure projects and be lifelong learners. The types of learning in case study discussions are discussing, practicing, and producing. In the modern digital era, discussions regarding the case can also be conducted online through breakout rooms. An online environment can also enable wider reach and accessibility options, such as typing their discussion points to those not comfortable publicly presenting their points.

Roleplays are an extension of case study discussions. A real-world problem or a hypothetical scenario can be considered. Here, the class is divided into different roles, and students take these roles and debate, considering the interests of these roles. For example, a role-play exercise for stakeholder engagement based on the Coimbatore metro rail project in India was recorded by Ninan et al. (2019). The students were divided into four stakeholder groups – the government, the main contractor, the chamber and the traveling public, and the owner and residents. The participants were given news articles and reports from their stakeholder groups to understand their respective stakeholders' interests and goals. Different exercises were carried out, such as drawing rich pictures, creating root definitions, and dealing with contradictions. After the exercise, the students claimed they could empathize with the different stakeholder groups and their concerns and develop critical thinking and teamwork. With role-play activities, professionals develop competencies such as being flexible and adaptable to change. They also empathized with social, political, and environmental concerns. The type of learning here is collaborating with team members and producing reports at the end of the exercise.

Problem-solving exercises can be based on live problems from the infrastructure sector or a hypothetical scenario. Here, students work either by themselves or together to solve the problem set by the instructor. For example, in a minor program on infrastructure at TU Delft, a real-world problem from the Rotterdam municipality was given to the students. The groups involved students from different specializations, such as mechanical engineering, public administration, informatics, spatial planning, and civil engineering. The problem-solving exercises helped students understand what issues are at stake and what to bring in from their disciplines. Each group then produces a solution to the problem after collaboration. Students dig deep into new areas and inquire about them. The final solution by the group is then presented to experts from the Rotterdam municipality, who provide additional comments and suggestions to the students. The problem-solving exercise helps cultivate decision-making capabilities in students and also enables them to be lifelong learners. Problem-solving exercises can help students understand how to solve real-world problems; for instance, the reconstruction of the Tsunami affected Yuriage area in Japan involved an interdisciplinary design charrette approach comprising five departments - Hydraulic, Geo-Sciences and Engineering, Transportation, Urban Drainage Engineering, and Urbanism (Hooimeijer et al., 2018). Similar to problem-solving exercises, problem-seeking exercises can also cultivate critical thinking in students.

Project work is a common activity for learning in infrastructure development. Generally, the instructor gives a problem for the students to work on for a period ranging from a couple of weeks to a maximum of a year. The project work can be carried out by a single student or as a group. The student must first collect current knowledge on the area through a literature review. Then, some data is collected and analysed to arrive at findings. The findings are discussed in a classroom presentation, and the student submits a report. The project activity helps students understand how different areas can come together to address concerns of infrastructure development. The type of learning in project work involves collaborating, inquiring and producing. The various activities for educating T-shape professionals and their types of learning and competencies are summarized in Table 2.

Education for managing infrastructure projects must embrace a more practical approach to project complexity and skills development instead of just theoretical knowledge from lectures (Geist and Myers, 2007). Learning activities such as on-site visits, role-plays, case study discussions, problem-solving exercises, and project work enable students to get practical insights. There can be more learning activities than those discussed above, such as games (Rumeser and Emsley, 2018) and simulations (Martin, 2000), to develop the competencies for building professionals in the infrastructure sector. These activities allow students to apply and practice their project management knowledge without the risk of failure (Jääskä and Aaltonen, 2022). It is critical that instructors in the field of infrastructure development document the type of learning and the competencies for each activity they introduce in classroom settings. The sudden transfer of physical education activities to online due to covid has resulted in largely negative responses from students, as noted by Minichiello et al. (2022), highlighting the importance of designing online learning activities which develop T-shape competencies for managing infrastructure projects.

Table 2
Activities for educating T-shape professionals for managing infrastructure projects.

Activities for learning	Types of learning	Competencies
Lectures	Acquiring	In-depth knowledge
On-site visits	Inquiring, Producing	Understand different areas, willingness to be life-long learners
Role-play	Collaborating, Producing	Flexible and adaptive to change
Case study discussions	Discussing, Practicing, Producing	Decision-making capabilities, understanding different areas, willingness to be life-long learners
Problem-solving exercises	Discussing, Inquiring, Practicing, Producing	Decision-making capabilities, willingness to be life-long learners
Project work	Collaborating, Inquiring, Producing	Understand different areas

6. Conclusion

The infrastructure development sector requires professionals who have the necessary specialization as well as possess a variety of skills to enable the completion of the project. This article aims to highlight the competencies required for infrastructure development. We argue that the competencies for infrastructure development are similar to those of T-shaped professionals. Infrastructure development professionals need to have in-depth knowledge of one discipline and essential knowledge of multiple disciplines. Competencies such as in-depth knowledge, ability to understand different areas, flexibility and adaptability to change, decision-making capabilities, and willingness to be life-long learners were instrumental in creating T-shaped infrastructure development professionals. The various learning activities such as lectures, on-site visits, role plays, case study discussions, problem-solving exercises and project work were employed to educate professionals in the area. While the current education practices focus on creating the depth of the T-shape, there is a need for more courses focusing on the breadth of the T-shape, which can include projects, role plays, internships, etc., where students get a sense of the real world and how they should collaborate with multiple disciplines to tackle a problem.

The study makes multiple contributions to pedagogy theory and practice in infrastructure development. First, the paper highlights that a T-shaped framework can be used to cultivate essential competencies for the management of infrastructure projects. The design of curricula for educational programs in the area can be anchored in the existing literature on T-shaped professionals in other sectors. Second, the theory of the T-shaped framework can be extended when applied to a complex setting such as infrastructure development. For example, the importance of vision is currently not highlighted as a T-shaped competency but is seen as important for infrastructure development and can be categorized in the decision-making capabilities of professionals. Third, we highlight how the different types of learning can be exercised through activities. Some designs, such as case studies, role plays, and problem-solving exercises, are discussed, which brings a cross between T-shape professionals and types of learning. Finally, we call on educators in the area to document the types of learning and competencies for each activity they introduce in classroom settings.

The emphasis on T-shaped professionals does not mean the extinction of I-shaped (or other shaped) professionals. While all types of professionals are required to manage infrastructure projects, we argue that T-shaped professionals are more apt to deal with the sector's challenges. Future research can trace the effectiveness of T-shape professionals in infrastructure development. The sector can be seen as a context where new forms of learning can be investigated and evidence observed. Such empirical evidence can extend our knowledge of T-shaped professionals and education for infrastructure development.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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