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RESEARCH ARTICLE

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Problem structuring in urban science education: Why, what, and how

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Abstract

Urban science is an emerging and transdisciplinary field that attracts deep interest in planning degree programs from educational institutions worldwide. Urban science education emphasizes the science of cities and urban information technology by integrating design, engineering, system science, spatial science, behavioral and social science, decision science, and other disciplines. The increasing complexity of urban systems creates significant pedagogical challenges for urban science education, particularly in problem structuring, which is the process of structuring, or defining, (a) the scope of the problem, (b) the potential ways for addressing the problem, and (c) suitable criteria for judging solutions to the problem. In this article, we describe the theoretical foundations of problem structuring in relation to urban science education and explain why it is difficult to teach. In response to this pedagogical challenge, we propose DIMES (Describe, Inquire, Model, Extract, and State), a novel domain-agnostic method combining design thinking and systems thinking developed for problem structuring in any level of higher education. We describe how the DIMES method can be integrated into urban science curricula with relation to critical considerations for teaching urban science problem structuring, the fast-evolving smart city development, and the disruptive impact of generative artificial intelligence on urban science education. Finally, we provide our thoughts on potential future studies with DIMES in urban science learning settings.

Keywords Higher education, Urban science education, Inquiry-based learning, Problem-based learning, Problem structuring

1 Introduction

1.1 Need and rationale

The modern world is characterized by volatility, uncertainty, complexity, and ambiguity (Bennett & Lemoine, 2014). Complex problems tend to be ill-structured; these are problems that are authentic (could or do exist in the real world), multidisciplinary, and complex, containing multiple components and interrelationships. Addressing such problems is an iterative process, resulting in the creation of artifacts, physical and/or digital. Solutions to ill-structured problems are never correct or incorrect, but rather better or worse, depending on inter-subjective success criteria which are agreed upon by a given group of people related to or affected by the problem (Jonassen, 2000). Problem structuring (or restructuring) is a crucial early step in addressing ill-structured problems effectively, because it allows for a new and more effective understanding of the problem at hand (Gilhooly, 2019). Accordingly, in recent decades, the need for employees with skills for addressing ill-structured problems has been widely recognized by national and international organizations (e.g., Di Battista et al., 2023; National Research Council, 2013; Nedelkoska & Quintini, 2018; Scott, 2015).

Higher-order thinking skills (HOTS) such as creative thinking, systems thinking, and critical thinking, among

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others (Barak et al., 2007) are non-algorithmic, complex modes of thought that involve generating multiple solutions, navigating uncertainty, applying multiple criteria, and engaging in reflection and self-regulation (Resnick, 1987; Arnold & Wade 2017). Active learning approaches, in which students engage in real-world (simple, simplified, or complex) problems, cases, or questions, carry out discourse with other students and reflect on their own learning, have been shown to help foster students' HOTS and problem-solving skills (Lavi et al., 2021a; Virtanen & Tynjala, 2019; Zhang & Ma, 2023). Still, in STEM (science, technology, engineering, and mathematics) education there remains a significant gap between students' academic achievement and their level of HOTS, including their ability to address real-world problems effectively (Winberg et al., 2019). This gap stems in part from instructors' struggles in implementing these methods due to challenges such as limited time for preparation and in-class activities, the perceived or actual difficulty in designing suitable problems and assessments, and balancing active learning with syllabus coverage, and in managing student resistance (Tharayil et al., 2018).

Cities are large open complex systems posing intricate challenges that involve various aspects of human habitat and related physical, ecological, social, and technical factors (Batty, 2005; Bettencourt, 2021; Wang et al., 2022). These dynamic complexities are further amplified by the rapid deployment of information technology, smart cities, and artificial intelligence, inevitably exacerbating the social-technical conflicts within contemporary urban living (Townsend, 2015). Consequently, urban science emerges as a field that aims to address such complexity by investigating urban phenomena through a more systematic lens with data-driven and computational approaches (Acuto et al., 2018; Batty, 2021; Long, 2019). The historical foundation of urban science can be traced back to the 1960s during the aerospace technology boom and the emergence of system science (De Monchaux, 2011). Contemporary urban science is closely linked to computational and data science, reflecting the broader shift toward data-driven, or data-intensive, scientific research—commonly referred to as the fourth paradigm of science (Bibri, 2019). Compared to traditional urban planning, urban science education approaches cities through the lens of complexity science, with two primary objectives: (1) to enhance the observation, documentation, analytics, and understanding of the complex organization and behavior of urban systems, positioning cities as scientific research subjects; and (2) to develop innovative solutions and smart city applications that address real-world challenges in urban planning, design, operation, policymaking, management, and governance. These dual aims underscore urban science's critical role in harnessing smart technologies to advance urban living. In general, urban science adopts a transdisciplinary approach integrating design, engineering, system science, spatial science, behavioral and social science, decision science, and other relevant disciplines (Kontokosta, 2021).

As far as we are aware, no peer-reviewed work has been published on teaching problem structuring in urban science education. We argue that the same need and challenges for teaching problem structuring that exist in STEM exist in urban science education in particular.

1.2 Research objective and research questions

This study sets out to (a) argue the need for teaching problem structuring in urban science education, and (b) propose a research-based methodology for doing this. Our research questions (RQs) are as follows:

- RQ1: Why teach problem structuring in urban science education?
- RQ2: What are the challenges in teaching problem structuring in urban science education?
- RQ3: How can problem structuring be taught effectively in urban science education?

Based on the above RQs, we present in this paper (a) the relevance and place of problem structuring in urban science and in urban science education, (b) key challenges for doing this effectively, and (c) a conceptual framework and methodology for doing this. We provide findings from workshops with urban science and architecture students where this methodology was applied to real-world problems. Finally, we discuss key conclusions, limitations, and future research directions.

Teaching problem structuring in urban science education.

1.3 Ill-structured problems in urban science

Traditional urban planning focuses on human settlement development, with particular emphasis on built environment, sustainability, equity, and quality of life (McLoughlin, 1969). Consequently, conventional planning education primarily addresses physical space, encompassing both the ecological and built environment, infrastructure, economic development, and policy (Taylor, 1998). Over the past three decades, rapid urbanization and technological advancements have created both opportunities and challenges for urban planning education. The surge in information and computing power—driven by big data, cloud computing, and artificial intelligence—has significantly expanded research resources and analytical capabilities for studying cities. In particular, the vast volume, velocity, and variety of urban

data have enabled a paradigm shift in urban research, fostering data-intensive scientific discovery and applied technological research and development. Meanwhile, cities are becoming increasingly complex, exhibiting new phenomena, generating new challenges, and displaying intricate dynamics that challenge conventional planning theories and methodologies. The rapid global development of smart cities has introduced socio-technical transformations that raise fundamental scientific questions about the interplay between environmental, technological, and social dynamics in human habitats.

As a result, the fast-growing field of urban science reflects an urgent intellectual and educational demand for integrating multiple disciplines and digital technologies to enhance our scientific understanding of cities. Since the 2010 s, many renowned international educational institutions have launched degree programs, specializations, certifications, or courses in urban science, such as Massachusetts Institute of Technology (MIT), New York University (NYU), University of Chicago, University College of London (UCL), Tsinghua University (THU), Hong Kong Polytechnic University (HKPU), and more. Despite the diverse urban science curriculums and research areas, these programs collectively highlight the two major interests, including (1) applied urban informatics or (2) science of cities. Applied urban informatics treat cities as living laboratories by leveraging scientific methods and information technology for urban instrumentation and intelligence. The heavy focus on data and information technology is commonly described as urban informatics by several institutions such as NYU, HKPU, Boston University (BU), and the University of Michigan. In contrast, the science of cities emphasizes understanding cities as complex adaptive systems, usually aiming to discover universal laws and patterns in the form, scale, network, and evolution of cities (Kutty et al., 2020; Morgan et al., 2024).

1.4 Problem structuring in urban science

Checkland (2000) distinguished between an 'obvious' problem, which requires finding a solution, and a problematic situation, which requires taking a course of action, as goal-seeking in this case is less relevant than in the case of a problem. Similarly, Jonassen (2000) suggested 'structuredness' as property of problems, with ill-structured problems, exemplified by dilemmas and design problems, having vague goals and multiple, uncertain solutions, while well-structured problems, exemplified by logical puzzles and algorithmic problems, have structured goals and a single, verifiable solution. While ill-structured problems tend to be more difficult than well-structured problems, this is not always the case, as problem difficulty depends on several factors apart from structuredness (Hung & Jonassen, 2008). According to Hung & Jonassen (2008), structuredness comprises of: (a) clarity or intransparency–how clear the problem states and problem-solving procedure are; (b) heterogeneity of interpretations–how many possible interpretations and perspectives the problem can have; and (c) interdisciplinarity–how many disciplines or domains the problem involves. Ill-structured problems tend to contain many unclear or unknown factors, have multiple interpretations, and be interdisciplinary (Hung & Jonassen, 2008; Savery, 2015).

Problem structuring plays a crucial role in urban science. Traditional urban planning strives to achieve a long-term balance among human development, natural resources, and societal harmony through principles of equity, justice, and fairness (Harvey, 1970). Conventional research and education encompass various disciplines, such as design (e.g., architecture, landscape architecture, urban design, environmental design), engineering (e.g., civil engineering, transportation engineering), and social science (e.g., sociology, public management, policy research). This multidisciplinary nature enables planners to address diverse problem types, particularly the complex and ambiguous "wicked" problems, i.e., ambiguous, multi-causal, and involving competing stakeholder interests (Skaburskis, 2008). Moreover, urban planning aims to tackle real-world problems that are characterized by rich contextual information and location-specific factors (Pl⊘ger, 2006). Thus, effectively structuring a problem requires a profound understanding of the local conditions and pertinent physical, technical, and social elements within a city or region.

1.5 Challenges with teaching problem structuring in urban science

Urban science brings forth new challenges when it comes to teaching problem structuring of design problems, mainly due to three key characteristics: transdisciplinary, data-driven, and techno-humanistic.

(1) Transdisciplinary: Urban science is an emerging field that integrates computer science, informatics, urban planning, social science, and other disciplines, fostering a diverse set of problem-solving skills (Karvonen et al., 2021). Design, for instance, differs from analytical problem-solving and engineering approaches by being particularly suited for addressing ill-structured problems (Portugali & Stokl, 2014). It aims to describe potential situations through conceptualization, representation, visualization, and communication.
(2) Data-driven: The proliferation of information technology and the accessibility of big data have sparked

an ongoing philosophical debate between problem-driven and data-driven methodologies, posing new challenges for problem structuring in urban planning education (Bunders & Varró, 2019). As big data and artificial intelligence increasingly shape scientific research, adapting problem structuring to leverage digital resources and data-driven approaches is essential in the fourth paradigm shift of urban science inquiry.

(3) Techno-humanistic: Urban science places a strong emphasis on technological deployment and smart city development, which require balancing physical, social, and technical considerations (Ojan & Lara-Navarra, 2022). These multifaceted challenges often result in ill-structured problems, encompassing issues such as data privacy, digital equity, cybersecurity, and algorithmic justice (Kitchin, 2016). Ensuring that urban science education equips students with the ability to navigate these rapidly evolving complexities remains an ongoing challenge.

Problem structuring is difficult in urban science education due to several reasons in the context of contemporary smart cities. Unlike well-structured problems (e.g., a math equation with a clear solution path), urban science problems are often wicked (Colding et al., 2019; Goodspeed, 2015). Common challenges exist during different problem structuring stages when students attempt to comprehend, approach, and weigh urban science problems. Urban science problems are dynamic, nonlinear, systematic, uncertain, or even counterintuitive, making it difficult for students to comprehend based on personal life experience or direct observation (Batty, 2009; Bettencourt, 2021). Therefore, structuring an urban science problem often requires a high-level cognitive load, critical thinking, and sufficient technical knowledge. Such complexity raises barriers for students, especially for undergraduate students or students with little urban living experience.

Unlike lab sciences, urban science has no fixed protocols for structuring problems, and may span across data science, sociology, economics, geography, ecology, engineering, and other related disciplines due to the transdisciplinary nature (Biberhofer & Rammel, 2017). As a result, there is a lack of standardized methods for approaching urban science problem structuring. Common teaching strategies often integrate design (iterative and user-centered), engineering (quantitative, solution, and optimization-focused), and social science (qualitative, participatory) approaches. In reality, students and even educators may lack sufficient expertise, leading to overcomplication.

Distinctive from natural science, urban science problems can be politically charged with subjectivity and multi-stakeholder conflicts (Saha et al., 2021). Since urban issues are viewed differently depending on different stakeholders (e.g., residents, policymakers, business operators, planners, and scientists), students may struggle to weigh trade-offs, competing interests, and ethical dilemmas (Lauria & Long, 2019; Lo Piccolo & Picone, 2023). In particular, undergraduate students with insufficient life experience and knowledge in social, cultural, historical contexts may struggle to structure an urban science problem within a proper scope and perspective. Consequently, teaching neutrality while acknowledging bias is challenging when structuring urban science problems.

Finally, cities provide distinct context in which the social construction of problems takes place, so problem discourses and policy analysis according to specific historical, spatial, and technical context, rather than naturalizing cities as objects (Shen, 1998). The shift from conventional urban planning to smart city development introduces new complexities due to technology, behavioral changes, and systemic uncertainties (Colding et al., 2020). Consequently, problem structuring for smart and future cities presents unique challenges due to the involvement of emerging technologies, untested use cases, and high levels of uncertainty. Rapid technological advancements such as AI, the Internet of Things (IoT), blockchain, autonomous vehicles (AVs), virtual reality (VR), and digital twins continually redefine problem landscapes (Table 1). However, students may lack adequate domain knowledge in these technologies or fall into the trap of solutionism, focusing on technology

Table 1 Problem model. (source: authors)

Element	Content
Process	1. Managing a household in an urban village (UV)
Stakeholders Who	S1: UV residents S2: UV businesses S2: Employers S3: City officials
Effect What	E1: Adverse health effects E2: High cost of AC E3: High cost of building maintenance E4: Social isolation
Location Where	L1: Buildings in UV L2: Asphalt streets in UV
Time When	T1: July and August T2: Days with heat-carrying winds
Cause Why	C1: Urban heat island effect C2: Lack of community in UV C3: High building density in UV C4: Lack of vegetation in UV C5: Large distance from UV to city cooling centers

itself rather than the underlying problem (León & Rosen, 2021). Unlike traditional urban challenges, smart city problems are more future-oriented, often characterized by unproven use cases and a lack of precedent (Szpilko, 2020). Consequently, students may struggle to develop meaningful hypothetical scenarios, sometimes conflating scientific reasoning with fictional thinking by overestimating the capabilities of these technologies.

2 Proposed methodology for teaching problem structuring in urban science education

2.1 Current approaches

Considering the differences between urban planning and urban science, discussions on pedagogical approaches to teaching urban science are still evolving. Urban science education tends to adopt diverse pedagogical approaches by integrating theory, technology, and real-world applications due to its transdisciplinary nature. Urban theory provides the conceptual and analytical foundation necessary to navigate the complexity of urban systems, making it indispensable in teaching problem structuring within urban science education (Batty, 2007). By grounding pedagogical approaches in theoretical frameworks, educators equip students with the tools to critically interpret, deconstruct, and reframe urban challenges. Common theory, such as complex adaptive systems (Bettencourt, 2021), human ecology (Colding, 2017), new urbanism (Bibri, 2019), and urban scaling (Bettencourt, 2013), empowers students to move beyond superficial analyses, fostering the ability to define problems with nuance, rigor, and ethical awareness.

Project-Based Learning (PtBL) is widely used in urban planning education because it effectively engages students and aligns with real-world problem-solving (Mahgoub, 2015; Teff-Seker et al., 2019). Many traditional planning courses are based in a studio environment with a real or simulated project, so PtBL connects planning education to local issues, leverage community environments as learning spaces, and foster hands-on practice, team collaboration, and critical minds reflecting on reality (Jones, 2019). In particular, urban planning education necessitates the inclusion of context-specific examples and case studies to help students grasp the unique characteristics and dynamics of diverse urban environments (Chen et al., 2020). For urban science education, PtBL seems to be a natural pedagogical match, since many urban science research projects are inherently applied, requiring students to tackle messy, real-world problems. The iterative, collaborative, and realistic nature of PtBL aligns with urban science's goal for better understanding cities and solving urban problems through scientific approaches (Bilandzic & Venable, 2011; Lewis, et al., 2018). However, it is necessary to acknowledge that PtBL is usually best for complex and applied urban challenges that require tangible solutions. Taking planning and design studio courses as an example, students are often given design tasks and required to develop design solutions or planning guidelines (Higgins et al., 2009).

While PtBL mirrors real-world urban planning practice and design workflow with clear outcomes, such learning experience may not be sufficient for urban science education. Lobo et al. (2020) reports a conference discussion about designing new urban science-related graduate programs in which discussants believe that continued development will require the training of new generations of urban scientists, and that both the content and manner of training will be different from established degree programs. In contrast, urban science emphasizes developing scientific reasoning and foundational knowledge of cities, exhibiting a distinctive focus when compared to conventional urban planning and design education. Overall, defining meaningful problems as the initial step in urban studies remains inconclusive and requires further experimentation and exploration.

2.2 Conceptual framework

The conceptual framework for the methodology proposed in this paper draws inspiration from several sources: Design problems as described by Jonassen (2000), design thinking's human-centered approach to problem-solving (Razzouk & Shute, 2012), hierarchical conceptual modeling of systems, inspired by *Object-Process Methodology* (Dori, 2016), system leverage points as described by Meadows (1999), and *problem-based learning*, or PbBL (Savery, 2015). DIMES is inspired by but does not directly copy from any of these sources.

In Jonassen's problem typology (2000), design problems are highly ill-structured—second only to dilemmas—authentic, i.e., could or do exist in the real world, multidisciplinary, and complex—containing multiple components and interrelationships. Addressing such problems is an iterative process, resulting in the creation of artifacts (physical and/or digital). Solutions to design problems are never 'correct' or 'incorrect', but rather better or worse, depending on inter-subjective success criteria which are agreed upon by a given group of people related to or affected by the problem. It is these kinds of problems that the proposed methodology was developed to address. In design thinking, the process of creating innovative products (or other artifacts) is centered around a thorough understanding of stakeholders' desires and behaviors. While design thinking processes tend to focus mostly on problem-solving, they do allow room for exploring and defining problems as part of this process (Razzouk & Shute, 2012).

Object Process Methodology (OPM) is a language and methodology rooted in model-based systems engineering (Dori, 1995). The OPM language, made up of things (objects and processes) and links between things (structural and procedural), is domain-agnostic and bimodal (textual and graphical). Through refinement and abstraction mechanisms, OPM allows for controlling modeling complexity by breaking down the conceptual representation of a system (its OPM system model) into sub-levels. Each such breakdown is represented by an Object-Process Diagram which shows how things are linked to each other in the system being modeled (Dori, 2016). OPM has previously been applied in STEM education, including science teacher education (Lavi & Dori, 2019), undergraduate engineering education (Lavi et al., 2020), and graduate engineering education (Lavi et al., 2021a). System leverage points (Meadows, 1999) are places within a complex system, where relatively little effort can produce a relatively large impact on the overall system outcomes. In this framework, potential leverage points can be arranged along an axis of effectiveness, from points that pertain to constants (e.g., taxes or standards), which are the least effective, to points pertaining to goals and mindset, which are the most effective.

Like PtBL, PbBL is a form of active learning. PbBL is a pedagogical approach where learners engage in addressing ill-structured problems without being provided with all (or any) of the required content before doing so. While PbBL allows more autonomy to learners than other forms of active learning (Kulak & Newton, 2014), with the instructor acting more as a facilitator than a mentor, it also tends to always be collaborative (Savery, 2015). PbBL is more suitable for teaching problem structuring than PtBL, as it more easily lends itself to addressing highly ill-structured problems.

2.3 Problem structuring method

DIMES stands for *Describe*, *Inquire*, *Model*, *Extract*, and *State*. This PbBL method was developed based on the conceptual framework described in the previous sub-section to provide a procedure and related materials for applying problem structuring instruction with STEM higher education students when addressing design problems.

DIMES is designed for higher education learning settings, from first-year education onward. The second author applied DIMES for the first time in an undergraduate course and on a problem related to sustainability. Since then, DIMES has been applied with undergraduate and graduate students in urban planning and architecture by both authors (this paper), with graduate students in systems engineering (manuscript in preparation), and with students and faculty in education (Lavi, 2025). The DIMES procedure is made up of five steps, and each one is accompanied by (a) instructions, (b) an assessment rubric, and (b) reflection items/questions. Steps and assessments are done in small teams, while reflections are done individually. For each step, a student team creates content (text or diagrams). Table 2 summarizes the DIMES steps and products. It should be noted that the DIMES method should ideally be carried out as an iterative process, where each subsequent step may inform potential changes to previous steps.

DIMES can be applied in 12 h, with two hours of instructor training. Implementing DIMES does not require special equipment or expensive digital resources. It can be applied, for example, within Microsoft Office (Word and PowerPoint), Google Docs (Docs and Slides), or Tencent Docs. However, a digital platform implementing DIMES exists as of 2025 (Lavi, 2025). Each assessment rubric includes multiple two categories of criteria, adherence—how well instructions for that step were followed independently of correctness, and correctness—how valid the content created during that step is. These assessments may be carried out by the instructor, by the student team, by a peer student team, or any combination thereof. Reflections focus on the learning process and on the subjective experience of the individual student. See Appendix for examples of an assessment rubric and of a reflection form.

Table 2 Key technology and comparative examples in traditional urban problems and smart city problems. (source: authors)

Key Technology	Traditional Urban Problems	Smart City Problems
Autonomous vehicles (AVs)	How to reduce traffic congestion?	How should AVs to be regulated in mixed-mode traffic condition?
Drones	Where to build a new subway station?	How to integrate drone delivery hubs into existing infrastructure?
Modular construction	How to increase affordable housing?	How to integrate modular homes with smart grid systems?
Data-driven or AI-aided decisions and operations	How to reduce crime in the neighborhood?	How to deploy predictive analytics without reinforcing bias?
Facial recognition	Where to install streetlights?	Should smart streetlights include facial recognition capability?
Algorithmic operation	Where to place solar panels?	How to balance energy trading grid with artificial intelligence dynamic pricing?

2.4 Training in methodology

DIMES training can be seamlessly integrated into courses or workshops, allowing students to learn how to frame ill-structured problems in an urban context and apply this method to more specific scenarios. In our case, instructors use extreme heat waves in Beijing as the context, providing essential background information on the phenomenon, its impact on the city, and urban responses for preparedness and mitigation. This foundational knowledge helps students develop a deeper understanding of the issue and relevant domain expertise. For example, the background information explains the multifaceted impacts of extreme heat waves, including their effects on human health, infrastructure, energy systems, ecosystems, economic activity, and social dynamics. By engaging with this broad spectrum of considerations, students gain a more comprehensive perspective on the complexity of the issue, rather than focusing narrowly on a single domain.

2.5 Example of application of methodology

The following example of implementing DIMES on a problem related to urban planning is based on workshops conducted by the authors with undergraduate and graduate students of urban planning and of architecture. The specific example is derived from students' work but was modified and refined by the authors.

2.5.1 Step #1: describe

The following problem description was provided by the first author, who is an urban science researcher and educator. In some large cities in China, numerous former rural villages are being rapidly urbanized along with the surrounding built environment due to the dualistic land system between urban and rural areas. These villages accommodate a large number of low-income migrants and are low-quality, high-density informal settlements. The crowded environment and hardening of roads in these villages aggravate the urban heat island effect, which is becoming worse due to increasingly frequent extreme heatwaves.

2.5.2 Step#2: inquire

The following is the gist of the problem case created during this step, based on the problem description created in step#1 as well as on external sources of information and scholarship:

1. Who are the stakeholders? UV residents (primary stakeholder groups), UV businesses (brick-and-mortar), their employers, and city officials.
2. What are the effects? Residents face adverse health effects, high air conditioning (AC) costs, costly building maintenance, and social isolation.
3. Where does the problem occur? Primarily within UV residential buildings and on asphalt streets.
4. When does the problem occur? Most critically in July and August, and during days with heat-carrying winds from the southwest, northwest, or southeast.
5. Why does the problem occur? Root causes include the UHI effect, limited community support, dense building configurations, lack of green spaces, and the UVs' distance from city cooling centers.

2.5.3 Step #3: model

Table 3 shows the top function of the problem model, including the top process, 'Managing a house in an urban village', and all the elements (five Ws) of the problem, as taken from the problem case created during Step#2.

Figure 1 shows the breaking down of the top function, which was continued for three more levels of depth, not shown herein for sake of brevity. The sub-function selected for further breakdown was '1.1. At-home staying', as it has the largest number of effects, i.e., has the largest impact on the problem. In case there is a tie between one or more sub-functions, each effect is scored as either '1' (weak) or '2' (strong), and the sum of all effects is compared between subfunctions. Failing that, the number

Table 3 DIMES stages, activities, and products. (source: authors)

Stage	Activity	Product
Describe	Describe the problem in a brief and unstructured way, using plain language	Problem description
Inquire	Inquire into the problem as a researcher, based on the five Ws (who, what, where, when, and why)	Case description
Model	Based on the case description, model the problem as a conceptual hierarchy of function, i.e., processes acting on objects—the five Ws	Conceptual hierarchical model
Extract	Extract leverage points (high impact-to-effort ratio), i.e., sub-functions deep within the model with which one could have a substantial impact on the problem with relatively little effort	List of leverage points
State	State the problem concisely and in a solution-neutral way based on the answers to the five Ws from the case description and on the list of leverage points	Problem statement

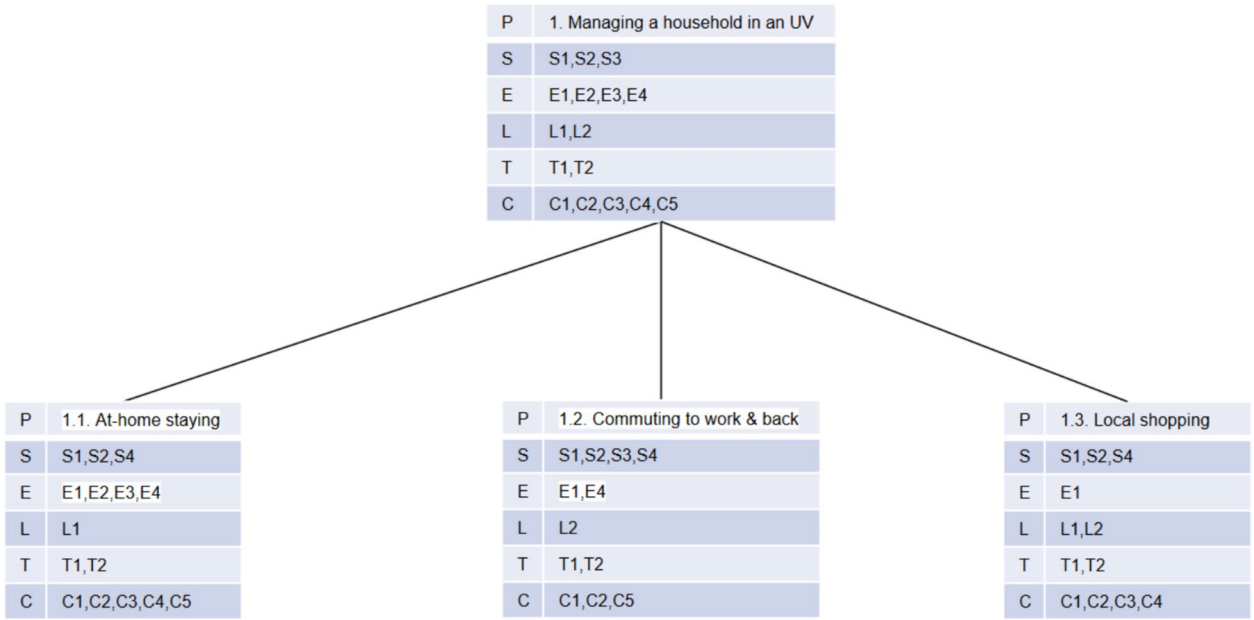

Fig. 1 Breakdown of the problem model's top function. (source: authors)

of other elements (stakeholders, locations, periods, and causes) is summed, and the subfunction with the least number of elements, i.e., requiring least effort to address, is broken down next.

Figure 2 shows the process tree of the problem model.

2.5.4 Step #4: extract

During this step, three sub-functions of the problem model were identified and selected for their high impact-to-effort ratio. The following rules, in the following prioritization, were applied to identify those leverage points:

1. Deeper within the model = smaller effort
2. Higher effect score = bigger impact
3. Includes less of the other elements (non-primary stakeholders, locations, times, and causes) = smaller effort
4. More initial in the causal chain = bigger impact

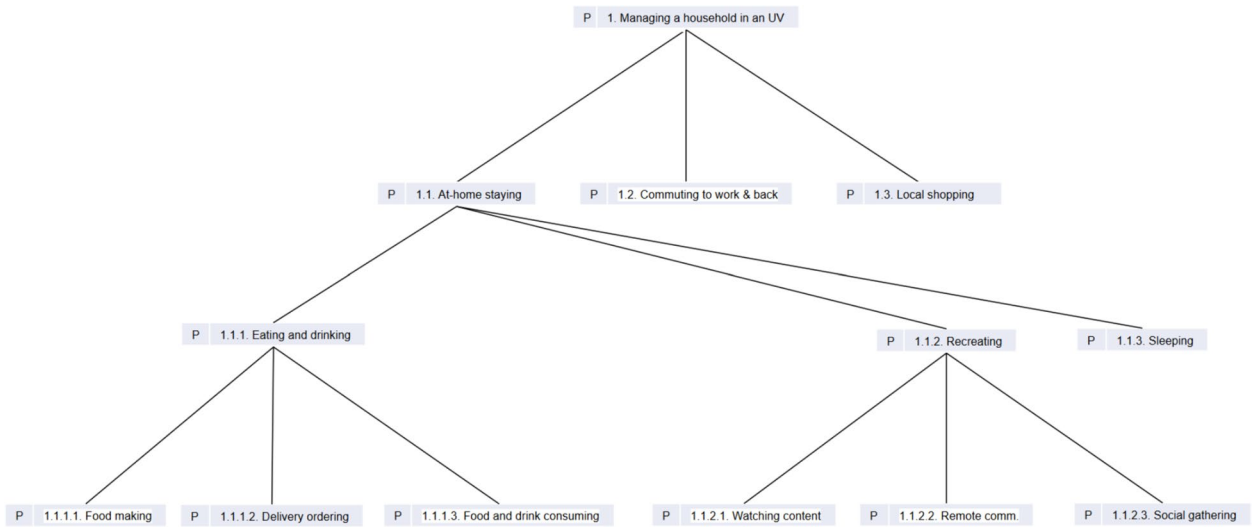

Fig. 2 Problem model's process tree. (source: authors)

Figure 3 shows the selected problem leverage points.

2.5.5 Step #5: state

The following statement was composed based on the problem case from Step#2 and selected problem leverage points from step#4.

> *"Residents of urban villages (UVs) in China are negatively affected by adverse health effects, high cost of air conditioning, high cost of building maintenance, and social isolation. The negative effects are caused by the urban heat island effect and the lack of community and vegetation in UVs, as well as the high building density in UVs and their large distance from cooling centers. The problem occurs mainly inside residents' homes during July and August, and in particular during days with heat-carrying winds."*

P	1.1.2.1. Watching content
S	S1,S4
E	E1(1),E2(2),E3(2),E4(2)
L	L1
T	T1,T2
C	C1,C2,C3,C4

P	1.1.2.2. Remote comm.
S	S1
E	E1(1),E2(2),E3(2),E4(1)
L	L1
T	T1,T2
C	C1,C2,C3,C4

P	1.1.1.3. Food and drink consuming
S	S1
E	E1(1),E2(1),E3(2),E4(2)
L	L1
T	T1,T2
C	C1,C2,C3,C4

Fig. 3 Problem leverage points. (source: authors)

3 Future research directions

Future research should expand DIMES implementation in urban science curricula and explore AI-assisted learning applications. The method trains students in structuring ill-structured problems through distinct cognitive processes: critical thinking during while drafting a problem case drafting (step 2. Inquire) and systems thinking during problem model creation (step 3. Model). These learning outcomes directly address workforce competencies identified outlined by Di Battista et al. (2023) and other studies of professional skill requirements. The digital platform implementing DIMES includes *generative artificial intelligence* (GAI) capabilities, using one of OpenAI's free GPT models via an application programming interface. Specifically, the platform includes a chatbot able to assess adherence in any step, thus enabling students to check their work as frequently as they like while also saving the instructor time. Future developments may include another chatbot for the instructor, acting as a facilitator of the DIMES process and a summarizer of student work and individual reflections. Consideration has been taken to define the role of GAI in the platform to that of a virtual teaching assistant, thus not replacing or mimicking the role of the instructor or of the student (Ye et al., 2024).

Urban science education faces both opportunities and challenges from accelerating artificial intelligence (AI) advancements (Ye et al., 2025). As DIMES primarily engages text-based content, large language models (LLMs) offer significant potential to scaffold problem structuring. However, educators must critically assess AI's broader societal, ethical, and pedagogical implications (Balsa-Barreiro et al., 2024). Peng et al. (2024) outline an AI integration spectrum from assisted to autonomized planning education, raising urgent questions: When should students employ LLMs for problem-solving? What foundational skills ensure responsible AI use for problem structuring? How might generative AI transform assessment practices? These dilemmas demand ongoing dialogue across institutions and instructors.

4 Conclusion

The growing complexity of urban systems underscores the critical need for innovating pedagogy in urban science education, particularly in addressing the challenges of problem structuring. As a transdisciplinary field intersecting design, technology, social sciences,

and systems thinking, urban science demands methods that equip students to navigate ambiguity, define problems holistically, and evaluate solutions in dynamic contexts. This study highlights how the DIMES (Describe, Inquire, Model, Extract, and State) method bridges design thinking and systems thinking to provide a structured yet flexible framework for problem structuring in higher education. By integrating iterative inquiry, systems modeling, and solution articulation, DIMES fosters the skills necessary to tackle multifaceted urban challenges while remaining adaptable to diverse disciplines and evolving contexts.

The integration of DIMES into urban science curricula aligns with the demands of fast-evolving smart city development and the disruptive potential of generative artificial intelligence (AI). These technologies not only reshape urban systems but also necessitate pedagogical strategies that balance technical proficiency with critical, ethical, and creative reasoning. Educators must emphasize collaborative, human-centered problem-solving while leveraging AI as a tool for data analysis, scenario generation, and decision support. There are still some research limitations, as it is too early to draw definitive conclusions about the long-term impact on students' career development and their ability to address real-world urban challenges due to the lack of longitudinal evidence. Future research should explore the longitudinal impacts of DIMES on student competencies, its scalability across institutional contexts, and its interplay with emerging technologies. Case studies examining its application in real-world urban projects, interdisciplinary collaborations, and AI-augmented learning environments will further refine its utility. By advancing problem structuring pedagogy, urban science education can empower future practitioners to address the interconnected, systemic challenges of cities—ensuring resilience, equity, and sustainability in an era of rapid urban transformation.

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Authors' contributions
All authors contributed to the study conception and design. The first draft of the manuscript was written by Yuan Lai and both authors contributed to the final manuscript. Both authors read and approved the final manuscript.

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Data availability
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Declarations

Ethics approval and consent to participate
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References

Acuto, M., Parnell, S., & Seto, K. C. (2018). Building a global urban science. *Nature Sustainability, 1*(1), 2–4.
Arnold, R. D., & Wade, J. P. (2017). A complete set of systems thinking skills. *Insight*, *20*(3), 9–17.
Balsa-Barreiro, J., Cebrián, M., Menéndez, M., & Axhausen, K. (2024). Leveraging generative ai models in urban science. *Principles and Advances in Population Neuroscience*, 239–75.
Barak, M., David, B. C., & Uri, Z. (2007). Purposely teaching for the promotion of higher-order thinking skills: A case of critical thinking. *Research in science education*, *37*(4), 353-369.
Batty, M. (2007). *Cities and complexity: understanding cities with cellular automata, agent-based models, and fractals*. The MIT press.
Batty, M. (2009). Cities as complex systems: Scaling, interaction, networks, dynamics and urban morphologies. In *Encyclopedia of complexity and systems science* (pp. 1041–71). Springer, New York, NY.
Batty, M. (2021). Defining urban science. In *Urban informatics* (pp. 15–28). Singapore: Springer Singapore.
Batty, M. (2005). *Cities and Complexity. Cambridge, Massachusetts*: The MIT Press.
Bennett, N., & Lemoine, J. (2014). What VUCA really means for you. Harvard business review, 92(1/2).
Bettencourt, L. M. (2013). The origins of scaling in cities. *Science, 340*(6139), 1438–1441.
Bettencourt, L. M. (2021). Introduction to urban science: evidence and theory of cities as complex systems.
Biberhofer, P., & Rammel, C. (2017). Transdisciplinary learning and teaching as answers to urban sustainability challenges. *International Journal of Sustainability in Higher Education, 18*(1), 63–83.
Bibri, S. E. (2019). The sciences underlying smart sustainable urbanism: Unprecedented paradigmatic and scholarly shifts in light of big data science and analytics. *Smart Cities, 2*(2), 179–213.
Bilandzic, M., & Venable, J. (2011). Towards participatory action design research: Adapting action research and design science research methods for urban informatics. *The Journal of Community Informatics, 7*(3), 1–20.
Bunders, D. J., & Varró, K. (2019). Problematizing data-driven urban practices: Insights from five Dutch 'smart cities.' *Cities, 93*, 145–152.
Chen, Y., Daamen, T. A., Heurkens, E. W., & Verheul, W. J. (2020). Interdisciplinary and experiential learning in urban development management education. *International Journal of Technology and Design Education, 30*(5), 919–936.
Colding, J., & Barthel, S. (2017). An urban ecology critique on the "Smart City" model. *Journal of Cleaner Production, 164*, 95–101.
Colding, J., Barthel, S., & Sörqvist, P. (2019). Wicked problems of smart cities. *Smart Cities, 2*(4), 512–521.
Colding, J., Colding, M., & Barthel, S. (2020). The smart city model: A new panacea for urban sustainability or unmanageable complexity? *Environment and Planning b: Urban Analytics and City Science, 47*(1), 179–187.
De Monchaux, N. (2011). *Spacesuit: Fashioning Apollo*. MIT press.
Di Battista, A., Grayling, S., Hasselaar, E., Leopold, T., Li, R., Rayner, M., & Zahidi, S. (2023). Future of jobs report 2023. In *World Economic Forum* (pp. 978–2).
Dori, D. (1995). Object-process analysis: Maintaining the balance between system structure and behaviour. *Journal of Logic and Computation*, *5*(2), 227-249.
Dori, D. (2016). *Model-based systems engineering with OPM and SysML* (Vol. 15). Springer.

Gilhooly, K. J. (2019). *Incubation in problem solving and creativity: Unconscious processes*. Routledge.
Goodspeed, R. (2015). Smart cities: Moving beyond urban cybernetics to tackle wicked problems. *Cambridge Journal of Regions, Economy and Society, 8*(1), 79–92.
Harvey, D. (1970). Social processes and spatial form: an analysis of the conceptual problems of urban planning. In *Papers of the Regional Science Association* (Vol. 25, No. 1, pp. 46–69). Berlin/Heidelberg: Springer-Verlag.
Higgins, M., Aitken-Rose, E., & Dixon, J. (2009). The pedagogy of the planning studio: A view from down under. *Journal for Education in the Built Environment, 4*(1), 8–30.
Hung, W., Jonassen, D. H., & Liu, R. (2008). Problem-based learning. In *Handbook of research on educational communications and technology* (pp. 485-506). Routledge.
Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development, 48*(4), 63–85.
Karvonen, A., Cvetkovic, V., Herman, P., Johansson, K., Kjellström, H., Molinari, M., & Skoglund, M. (2021). The 'New Urban Science': Towards the interdisciplinary and transdisciplinary pursuit of sustainable transformations. *Urban Transformations, 3*, 1–13.
Kitchin, R. (2016). The ethics of smart cities and urban science. *Philosophical Transactions of the Royal Society a: Mathematical, Physical and Engineering Sciences, 374*(2083), 20160115.
Kontokosta, C. E. (2021). Urban informatics in the science and practice of planning. *Journal of Planning Education and Research, 41*(4), 382–395.
Kutty, A. A., Abdella, G. M., Kucukvar, M., Onat, N. C., & Bulu, M. (2020). A system thinking approach for harmonizing smart and sustainable city initiatives with United Nations sustainable development goals. *Sustainable Development, 28*(5), 1347–1365.
Kulak, V., & Newton, G. (2014). A guide to using case-based learning in biochemistry education. *Biochemistry and molecular biology education*, *42*(6), 457-473.
Lauria, M., & Long, M. F. (2019). Ethical dilemmas in professional planning practice in the United States. *Journal of the American Planning Association, 85*(4), 393–404.
Lavi, R., & Dori, Y. J. (2019). Systems thinking of pre- and in-service science and engineering teachers. *International Journal of Science Education, 41*(2), 248–279.
Lavi, R., Dori, Y. J., Wengrowicz, N., & Dori, D. (2020). Model-based systems thinking: Assessing engineering student teams. *IEEE Transactions on Education*, *63*(1), 39-47.
Lavi, R., Dori, Y. J., & Dori, D. (2021a). Assessing novelty and systems thinking in conceptual models of technological systems. *IEEE Transactions on Education, 64*(2), 155–162.
Lavi, R. (2025). Evaluating the perceived efficacy and usability of an AI-enhanced platform for design learning management. Paper presented at the Clive L. Dym Mudd Design Workshop XIV, Claremont, CA.
León, L. F. A., & Rosen, J. (2021). Technology as ideology in urban governance. In *Smart Spaces and Places* (pp. 166–75). Routledge.
Lewis, D. G. R., Gorson, J., Maliakal, L. V., Carlson, S. E., Gerber, E. M., Riesbeck, C. K., & Easterday, M. W. (2018). Planning to iterate: Supporting iterative practices for real-world ill-structured problem-solving. *Rethinking Learning in the Digital Age. Making the Learning Sciences Count*, *2018*, 9.
Lo Piccolo, F., & Picone, M. (2023). Ethical Dilemmas in Urban Studies. In *Ethics in Research: Principles and Practical Considerations* (pp. 71–9). Cham: Springer Nature Switzerland.
Lobo, J., Alberti, M., Allen-Dumas, M., Arcaute, E., Barthelemy, M., Bojorquez Tapia, L. A., & Youn, H. (2020). Urban science: Integrated theory from the first cities to sustainable metropolises.
Long, Y. (2019). (New) Urban Science: Studying "New" Cities with New Data, Methods, and Technologies. *Landscape Architecture Frontiers*. https://doi.org/10.15302/J-LAF-20190202
Mahgoub, Y. (2015). Project based learning for urban design education: Resilient cities under rapid urban change, the case of Doha, Qatar. In *2015 International Conference on Interactive Collaborative Learning (ICL)* (pp. 407–412). IEEE.
Meadows, D. (1999). Leverage points: Places to intervene in a system. Sustainability Institute. https://donellameadows.org/wp-content/userfiles/Leverage_Points.pdf
McLoughlin, J. B. (1969). Urban and regional planning. A systems approach.
Morgan, M. J., Stratford, E., Harpur, S., & Rowbotham, S. (2024). A systems thinking approach for community health and wellbeing. *Systemic Practice and Action Research, 37*(2), 161–183.
National Research Council. (2013). Education for life and work: Developing transferable knowledge and skills in the 21st century. Washington, DC: National Academies Press.
Nedelkoska, L., & Quintini, G. (2018). *Automation, skills use and training* (Vol. 202). OECD Publishing.
Ojan, M. P., & Lara-Navarra, P. (2022, April). Design thinking, soft skills development, and the digital society. In *The International Research & Innovation Forum* (pp. 759–66). Cham: Springer International Publishing.
Peng, Z. R., Lu, K. F., Liu, Y., & Zhai, W. (2024). The pathway of urban planning AI: From planning support to plan-making. *Journal of Planning Education and Research, 44*(4), 2263–2279.
Pl⊘ger, J. (2006). Urban planning and urban life: Problems and challenges. *Planning Practice and Research, 21*(2), 201–222.
Portugali, J., & Stolk, E. (2014). A SIRN view on design thinking—an urban design perspective. *Environment and Planning b: Planning & Design, 41*(5), 829–846.
Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important? *Review of Educational Research, 82*(3), 330–348.
Resnick, L. B., & Science National Research Council (US). Committee on Research in Mathematics. (1987). Education and learning to think.
Saha, M., Chauhan, D., Patil, S., Kangas, R., Heer, J., & Froehlich, J. E. (2021). Urban accessibility as a socio-political problem: A multi-stakeholder analysis. *Proceedings of the ACM on Human-Computer Interaction, 4*(CSCW3), 1–26.
Savery, J. R. (2015). Overview of problem-based learning: Definitions and distinctions. *Essential readings in problem-based learning: Exploring and extending the legacy of Howard S. Barrows*, *9*(2), 5–15.
Scott, C. L. (2015). The futures of learning 2: What kind of learning for the 21st century.
Shen, Q. (1998). Spatial technologies, accessibility, and the social construction of urban space. *Computers, Environment and Urban Systems, 22*(5), 447–464.
Skaburskis, A. (2008). The origin of "wicked problems." *Planning Theory & Practice, 9*(2), 277–280.
Szpilko, D. (2020). Foresight as a tool for the planning and implementation of visions for smart city development. *Energies, 13*(7), 1782.
Taylor, N. (1998). *Urban planning theory since 1945*. Sage Publications.
Teff-Seker, Y., Portman, M. E., & Kaplan-Mintz, K. (2019). Project-based learning in education for sustainable development: A case study of graduate planning students. *Case Studies in the Environment*. https://doi.org/10.1525/cse.2018.001537
Townsend, A. (2015). Cities of data: Examining the new urban science. *Public Culture, 27*(2), 201–212.
Tharayil, S., Borrego, M., Prince, M., Nguyen, K. A., Shekhar, P., Finelli, C. J., & Waters, C. (2018). Strategies to mitigate student resistance to active learning. *International journal of STEM education*, *5*(1), 7.
Virtanen, A., & Tynjälä, P. (2019). Factors explaining the learning of generic skills: a study of university students' experiences. *Teaching in Higher Education*.
Wang, G., Li, F., Gao, N., & Liu, X. (2022). Perspective on study of urban science. *Bulletin of Chinese Academy of Sciences (Chinese Version), 37*(2), 177–187.
Winberg, C., Adendorff, H., Bozalek, V., Conana, H., Pallitt, N., Wolff, K., & Roxå, T. (2019). Learning to teach STEM disciplines in higher education: A critical review of the literature. *Teaching in Higher Education*, *24*(8), 930-947.
Ye, X., Zhai, W., Du, J., Van Zandt, S., & Ye, Y. (2024). Authentic or artificial intelligence? Faculty's perspectives on the ChatGPT's impact on US urban planning Ph. d. programs. *Frontiers of Urban and Rural Planning, 2*(1), Article 23.
Ye, X., Yigitcanlar, T., Goodchild, M., Huang, X., Li, W., Shaw, S. L., Fu, Y., Gong, W., & Newman, G. (2025). Artificial intelligence in urban science: Why does it matter? *Annals of GIS*. https://doi.org/10.1080/19475683.2025.2469110
Zhang, L., & Ma, Y. (2023). A study of the impact of project-based learning on student learning effects: A meta-analysis study. *Frontiers in psychology*, *14*, 1202728.

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