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Digital Twins as Integrative Learning Artifacts in Systems Education

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Abstract

Digital twins (DTs)—dynamic digital representations of physical systems—are increasingly used in organizational contexts to support monitoring, simulation, and data-driven decision-making. Despite their growing relevance, digital twin concepts remain underrepresented in undergraduate Information Systems (IS) curricula, limiting students' opportunities to develop integrated competencies in systems thinking, data integration, digital infrastructure, and governance. This paper proposes a structured instructional framework for integrating digital twin education into undergraduate IS programs, grounded in both the IS 2010 Curriculum Guidelines and the IS 2020 Competency Model. The framework emphasizes (1) clearly defined student learning outcomes aligned with IS competencies, (2) foundational instruction in digital twin architecture and system integration, and (3) experiential learning through hands-on laboratories and project-based activities supported by affordable and scalable learning kits. A comparative taxonomy of commonly used digital twin platforms is presented to assist educators in selecting instructional tools aligned with curricular goals and resource constraints. An illustrative classroom implementation demonstrates how digital twin learning artifacts can support experiential learning while reinforcing core IS competencies in data management, systems integration, human-centered decision-making, and governance. The paper concludes by discussing educational implications and future directions for integrating digital twins into undergraduate IS education.

Keywords: Digital Twin, Curriculum integration, Educational Technology, Project-based Learning, Learning Kits, Hands-on Learning

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Digital Twins as Integrative Learning Artifacts in Systems Education

Biju Bajracharya and Mohammad Moin Uddin

1. INTRODUCTION

Digital transformation has reshaped how organizations design, operate, and optimize complex systems, particularly through the integration of cyber-physical assets, real-time data streams, and advanced analytics. Among the technologies driving this transformation, digital twins (DTs) have emerged as a critical enabler of monitoring, simulation, and continuous improvement of physical systems. A digital twin is commonly described as a dynamic digital representation of a physical entity that is continuously updated through bidirectional data exchange between the physical and digital environments (Grieves, 2014). Advances in the Internet of Things (IoT), cloud computing, and data analytics have significantly accelerated the development and adoption of digital twins across sectors such as smart infrastructure, manufacturing, healthcare, energy management, transportation, and academic settings (Tao et al., 2019; Zhang et al., 2023; National Academies of Sciences, Engineering, and Medicine, 2024; Schalkwyk, 2024).

The digital twin concept was formalized by Grieves (2014), who described it as a system comprising a physical entity, its digital counterpart, and the data connections that enable continuous interaction between them. Since then, the concept has evolved beyond static digital models toward dynamic, data-driven systems capable of reflecting current operational conditions and, in some cases, anticipating future behavior. Tao et al. (2019) characterize digital twins as integrated, multiscale simulations that combine real-time sensor data, historical records, and analytical models to mirror the behavior and lifecycle of a physical system. This evolution positions digital twins not merely as visualization artifacts, but as operational information systems that support diagnostics, optimization, and strategic decision-making within complex organizational environments.

While digital twins have been widely studied in engineering and manufacturing (MIT Open Learning, 2024; Omran et al., 2024; Hazrat et al., 2023), they have received relatively limited attention in other domains. As organizations increasingly adopt digital twin platforms, graduates are expected to understand how physical data sources, digital infrastructures, analytics engines, and governance mechanisms interact within enterprise systems. However, in many undergraduate Information Systems (IS) programs, related topics—such as systems analysis, data management, IoT, and emerging technologies—are introduced independently, without an explicit integrative framework that reflects real-world cyber-physical systems (Liu et al., 2021; Jankovskis et al., 2024). As a result, students may graduate with familiarity across individual technologies but have limited experience designing or reasoning about systems that bridge physical operations and digital decision infrastructures.

Recent updates to undergraduate IS curriculum guidance further underscore this gap. The IS 2020 Competency Model shifts emphasis from prescriptive course structures toward demonstrable competencies that graduates should exhibit upon degree completion, aligning IS education with evolving organizational and societal needs. Core IS 2020 competencies—including systems thinking, data integration, digital infrastructure, security, and organizational alignment—map directly to the capabilities required for effective digital twin design and deployment. From this perspective, digital twins represent a natural extension of contemporary IS education rather than an external or specialized topic confined to engineering-centric domains, because they directly reinforce the systems thinking, data integration, and organizational alignment emphasized in modern IS curriculum guidance (Topi et al., 2020).

Although this work is primarily grounded in the IS 2020 Competency Model, it also acknowledges the continued relevance of the IS 2010 Curriculum Guidelines, which remain in use across many undergraduate IS programs. IS 2010 established foundational competencies in systems analysis, data management, and organizational context that continue to underpin contemporary IS education. The IS 2020 model builds upon this foundation by emphasizing digital transformation, data-driven systems, platform ecosystems, and societal impact. Digital twin

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education aligns with both models—extending traditional IS competencies articulated in IS 2010 while directly supporting the competency-based, transformation-oriented emphasis of IS 2020. Recognizing this continuity allows digital twins to be integrated into IS curricula without requiring wholesale restructuring, consistent with the evolutionary curriculum perspective articulated in IS 2010 and extended in the IS 2020 competency model (Topi et al., 2010; Topi et al., 2020).

Despite this strong conceptual alignment, educators face significant challenges when attempting to incorporate digital twin instruction into undergraduate IS curricula. Digital twin systems are inherently multidisciplinary, requiring integration of real-time data acquisition, system modeling, platform interoperability, cybersecurity, and visualization. Additional barriers include the diversity and cost of available platforms, limited faculty familiarity with digital twin ecosystems, and uncertainty regarding how to design hands-on learning experiences that are accessible, scalable, and pedagogically coherent (Hadfield, 2020; Jankovskis et al., 2024). Without structured instructional guidance, digital twin concepts risk being addressed superficially or framed as advanced engineering topics beyond the scope of traditional IS programs.

This paper addresses these challenges by proposing a structured instructional framework for integrating digital twin education into undergraduate IS programs grounded in the IS 2020 Competency Model. The framework consists of three interrelated components: (1) student learning outcomes explicitly mapped to IS 2020 competencies; (2) foundational digital twin concepts emphasizing systems architecture and data flow; and (3) hands-on laboratories and project-based learning activities supported by affordable and scalable digital twin learning kits. Rather than positioning digital twins as an advanced specialization, this approach embeds digital twin concepts within core IS domains, reinforcing existing competencies while exposing students to emerging cyber-physical systems.

In addition, this study presents a comparative taxonomy of commonly used digital twin platforms and educational kits, examining their cost, technical requirements, instructional affordances, and alignment with IS competencies. A classroom-based example further illustrates how low-cost digital twin kits can be incorporated into project-based learning activities, enabling students to explore real-time data integration, system interaction, and applied decision-making. These contributions provide a practical and replicable approach for aligning undergraduate IS education with evolving workforce demands shaped by intelligent, connected, and data-driven systems. This study contributes a competency-aligned instructional framework, a dual IS 2010–IS 2020 curriculum mapping, and an experiential digital twin learning model suitable for undergraduate IS programs.

2. DIGITAL TWIN CURRICULUM DESIGN

The growing use of digital twin (DT) technologies in domains such as smart infrastructure, healthcare, and energy systems has created new expectations for Information Systems (IS) graduates. As digital twins increasingly shape how organizations monitor operations, integrate heterogeneous data sources, and support decision-making, IS professionals are expected to understand how physical systems, digital platforms, analytics, and organizational processes interact within enterprise environments. These developments motivate the integration of digital twin concepts into undergraduate IS curricula.

Unlike earlier curricular models that emphasized prescribed course structures, the IS 2020 Competency Model adopts a competency-based approach that prioritizes demonstrable capabilities over specific technologies, reflecting the long-standing IS emphasis on adaptable, transferable skills (Topi et al., 2010; Topi et al., 2020). This orientation provides a suitable foundation for incorporating digital twins into IS education, as DT systems inherently require integrated competencies such as systems thinking, data integration, digital infrastructure, and governance. At the same time, many IS programs continue to draw on the foundational structure articulated in IS 2010, particularly in areas such as systems analysis, data management, and organizational context. Digital twin instruction can therefore function as a connective element between these models, extending foundational IS competencies toward contemporary cyber-physical applications.

Digital twin systems combine physical assets, sensing technologies, digital platforms, data pipelines, analytics, and organizational processes. Prior research suggests that DT-related instruction is often fragmented, with components such as simulation, IoT, or analytics introduced independently and without an explicit integrative framework that reflects operational systems in practice (Liu et al., 2021; Jankovskis et al., 2024; Ahmed & Zaidi, 2025). From an IS 2020 perspective, this fragmentation constrains

students' ability to apply systems thinking and to reason about integrated digital solutions in organizational contexts, a concern explicitly raised in prior IS curriculum discussions emphasizing integration across technical and organizational domains (Topi et al., 2010; Topi et al., 2020).

In response, this paper proposes a structured instructional framework for digital twin education in undergraduate IS programs. The framework consists of three interrelated elements: (1) explicitly defined student learning outcomes aligned with IS competencies, (2) instruction in digital twin architecture and system integration, and (3) hands-on laboratories and project-based learning activities supported by accessible and scalable learning kits. Rather than positioning digital twins as a specialized or advanced topic, the framework embeds DT concepts within core IS domains, reinforcing existing competencies while exposing students to cyber-physical systems that are increasingly central to digital transformation.

Student Learning Outcomes (SLOs)

To further operationalize the SLO categories, the following learning objectives provide measurable outcomes for undergraduate IS students:

1. Design a basic DT-enabled data pipeline that integrates data from physical or simulated sources into a digital platform.
2. Analyze system behavior using real-time or simulated data to support operational or managerial decision-making.
3. Develop and interpret visualizations (e.g., dashboards, digital representations) that reflect system state and performance.
4. Evaluate DT-based solutions in terms of data quality, security, interoperability, and organizational impact.
5. Justify system design decisions by considering technical constraints, governance requirements, and user needs.

These objectives translate high-level competencies into actionable outcomes that can guide instructional design and assessment.

Effective digital twin curriculum design should be grounded in clearly articulated student learning outcomes (SLOs) that align with the IS 2020 competency framework, which emphasizes competency demonstration, integration, and organizational relevance as defining characteristics of undergraduate IS education (Topi et al., 2020).

Drawing on the IS 2020 Competency Model and prior work on digital twin education (Liu et al., 2021), this study identifies three learning outcome categories that support DT instruction in undergraduate IS programs.

SLO1: Data Integration and Management

- Collecting, cleaning, and synchronizing data across physical and digital platforms.
- Managing and synchronizing real-time IoT data streams while ensuring data quality and consistency.
- Applying knowledge of IoT architectures and sensor networks to support integrated information systems.

SLO2: System Modeling, Simulation, and Digital Infrastructure

- Developing conceptual and data-driven representations of physical assets, processes, or systems using appropriate IS-oriented tools and techniques.
- Analyzing system behavior and performance through scenario-based reasoning, dashboards, and data-driven feedback mechanisms.
- Utilizing accessible tools such as spreadsheet-based models, Python-based data analysis, low-code platforms, or cloud-based DT services to support system understanding and decision-making.
- Interpreting system dynamics and analytics outputs to evaluate alternative operational or design scenarios.

SLO3: Cybersecurity and System Interoperability

- Applying secure data exchange practices to protect digital twin systems and associated data assets.
- Identifying interoperability challenges when integrating digital twin platforms across heterogeneous systems and environments.
- Demonstrating awareness of organizational, ethical, and risk considerations in digital twin development (e.g., OPC UA, BIM, ISO 23247).
- Integrating DT solutions across platforms and organizational boundaries while considering governance and security constraints.

The classroom digital twin implementation further illustrates the competency mappings summarized in Table 2.1. At the introductory level, students focused on real-time data ingestion, validation, and visualization, directly reinforcing SLO1 (Data Integration and Management). Intermediate activities required students to reason about system behavior, spatial context, and feedback loops between physical and digital components, supporting SLO2 (System Modeling, Simulation,

and Digital Infrastructure). Advanced tasks emphasized secure data exchange, cross-platform integration, and the design of transparent operational policies, aligning with SLO3 (Cybersecurity, Interoperability, and Governance). This progression demonstrates how a single digital twin learning artifact can support multiple IS 2020 competencies through scaffolded experiential learning.

Fundamentals of Digital Twin Architecture and System Integration

To support the identified learning outcomes, instruction in digital twin fundamentals introduces students to the core architectural elements of DT systems, including physical assets, sensing and data acquisition layers, digital representations, analytics and simulation components, and visualization or interaction interfaces. Building on Grieves' (2014) conceptual model and subsequent refinements (Tao et al., 2019), students examine how data flows between physical and digital domains and how insights generated by the digital twin inform operational and managerial decision-making.

A central instructional consideration involves determining which competencies to emphasize within limited curricular space. The IS 2020 model encourages programs to prioritize transferable capabilities—such as systems thinking, integration, and organizational alignment—over tool-specific training (Topi et al., 2020). Consistent with this guidance, the

Category	DT Competency Area	Description	IS 2010 Alignment	IS 2020 Core Area Alignment
Student Learning Outcomes (SLOs)	SLO1: Data Integration & Management	Collecting, cleaning, and synchronizing IoT and operational data; ensuring data quality and real-time access	Data and Information Management; Systems Analysis & Design	Data Integration; Data-Driven Decision Making
	SLO2: System Modeling, Simulation, and Digital Infrastructure	Creating and maintaining digital representations of physical systems; basic simulation and predictive reasoning	Systems Analysis & Design; IT Infrastructure	Solution Development; Digital Infrastructure; Systems Thinking
	SLO3: Cybersecurity & Interoperability	Secure data exchange, cross-platform integration, governance, and risk mitigation.	IS Risk Management; IT Infrastructure	Risk Management; Ethics & Professional Responsibilities; Enterprise Integration
Digital Twin Architectural Concepts	Fundamentals: System Architecture & Connectivity	Designing cyber-physical architecture; sensor integration; data pipelines	IT Infrastructure; Systems Analysis & Design	Digital Infrastructure; Systems Thinking
	Fundamentals: Visualization & Interaction	Dashboards, 3D models, and interactive interfaces supporting decision-making	Data and Information Management	Human-Centered Design; Solution Development
	Cybersecurity & Ethical Considerations	Ensuring secure, interoperable, and responsible DT deployments	Data and Information Management	IS Risk Management & Security; IT Strategy, Management & Acquisition
	Fundamentals: Diagnostics & Analytics	Monitoring, anomaly detection, predictive insights, and decision support	Systems Analysis & Design	Analytics; Data-Driven Decision Making

Table 2.1 Mapping of DT Learning Outcomes and Architectural Concepts to IS 2020 Curriculum Areas

proposed framework emphasizes architectural reasoning, data flow, interoperability, and governance rather than mastery of any single digital twin platform. This approach supports conceptual understanding that is applicable across industries and remains resilient to changes in specific tools or technologies.

By grounding digital twin learning outcomes and architectural concepts in established IS curriculum models, digital twin education can be positioned squarely within the IS discipline rather than framed as an external or engineering-centric topic. This alignment reinforces the role of IS programs in preparing graduates to design, manage, and govern complex digital systems that connect physical operations with organizational decision-making.

Mapping DT Fundamentals to IS Curriculum Models (IS 2010 and IS 2020)

While this instructional framework is primarily aligned with the IS 2020 Competency Model, explicit mapping to the IS 2010 curriculum structure remains important for programs that continue to use IS 2010 as a foundational reference. Accordingly, the competencies emphasized in DT instruction can be mapped to both IS curriculum models, demonstrating continuity rather than replacement. Under IS 2010, DT learning outcomes align with core areas such as Data and Information Management, Systems Analysis and Design, IT Infrastructure, and IS Risk Management (Topi et al., 2010). These same outcomes map naturally to IS 2020 competencies related to systems thinking, data integration, digital infrastructure, and organizational alignment (Topi et al., 2020). This dual alignment illustrates how digital twin education can be adopted incrementally, supporting contemporary competency development while remaining compatible with existing IS program structures. Table 2.1 summarizes this dual alignment by mapping digital twin learning outcomes and foundational competencies to IS 2010 core curriculum areas and their corresponding IS 2020 competency domains, illustrating how digital twin concepts can be integrated incrementally within existing IS programs.

Instructional Context and Prerequisites

The proposed framework is designed for upper-level undergraduate Information Systems courses, including Systems Analysis and Design, Data Management, Emerging Technologies, or Capstone experiences. Students are expected to have foundational knowledge in introductory programming, basic data management, and core IS concepts such as systems thinking and information flow. This positioning allows digital twin concepts to function as an integrative layer that connects prior learning across technical and organizational domains.

3. EXPERIENTIAL LEARNING AND DIGITAL TWIN INSTRUCTION

Experiential learning is a central element of the IS 2020 competency model, which emphasizes applied problem-solving, systems thinking, and the ability to integrate digital solutions within organizational contexts. Within this framework, hands-on laboratories and project-based learning function as primary instructional mechanisms through which students develop and demonstrate Information Systems competencies, rather than supplementary activities. DT learning kits offer a practical way to support this approach by enabling students to engage directly with cyber-physical systems that integrate data, infrastructure, analytics, and decision processes.

Figure 3.1 illustrates a conceptual digital twin learning architecture that supports experiential learning and human-centered decision-making in undergraduate IS education. The figure illustrates the integration of a physical environment, data integration layer, digital twin representation, and human-centered decision and governance processes. The architecture emphasizes systems thinking, real-time data flow, and human oversight rather than tool-specific implementation details, aligning digital twin instruction with IS 2020 competency development.

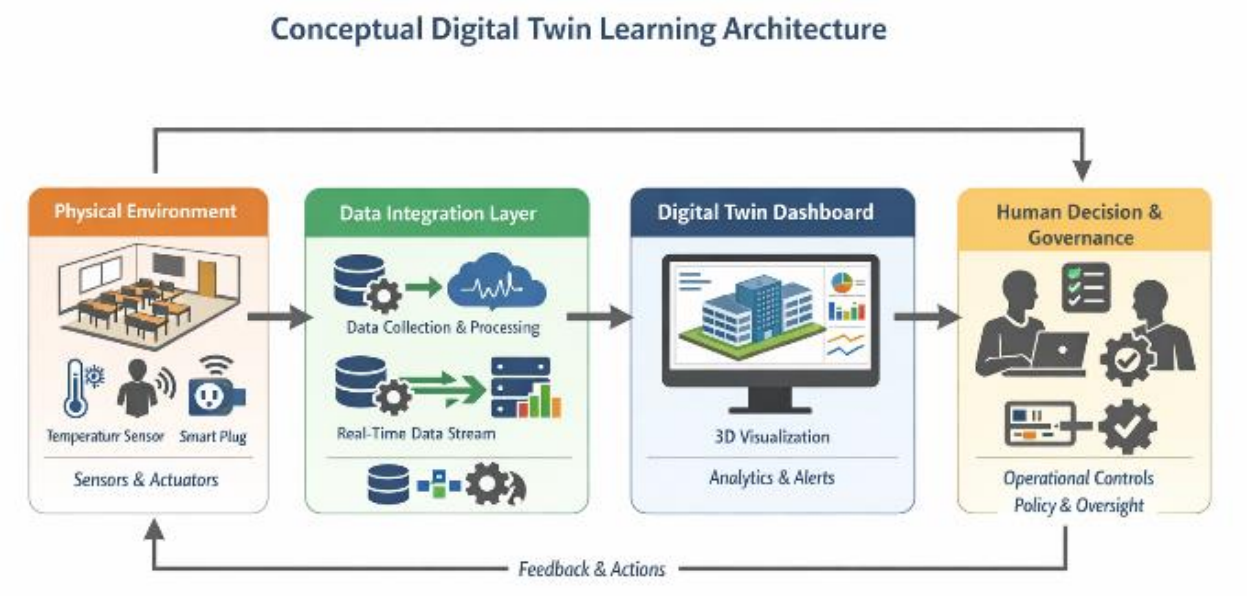


Figure 3.1 Conceptual Digital Twin Learning Architecture.

DT learning kits serve as accessible entry points for experiential learning by enabling students to design, observe, and interact with digital representations of physical systems. When incorporated deliberately into course design, these kits can support multiple IS 2020 competencies, including data integration, digital infrastructure, solution development, and organizational alignment. In contrast to purely simulated environments, DT kits expose students to real-time data flows, system constraints, and integration challenges that more closely resemble those encountered in organizational settings. This exposure helps students move beyond abstract conceptualization toward applied systems reasoning.

From an instructional standpoint, the pedagogical value of DT learning kits lies less in the sophistication of the underlying hardware and more in their capacity to support learning progression. Introductory activities may focus on foundational tasks such as data acquisition, basic integration, and visualization, aligning with learning outcomes related to data and information management (SLO1). More advanced projects can then introduce system modeling, analytics, security considerations, and cross-platform integration, supporting learning outcomes associated with systems thinking and risk management (SLO2 and SLO3). This staged approach is consistent with IS 2020's emphasis on competency development over tool-specific training and encourages the development of transferable skills applicable across technologies and organizational contexts.

DT learning kits provide affordable and scalable entry points for experiential learning, enabling students to design, monitor, and control virtual replicas of physical systems. Platforms such as Arduino, Raspberry Pi, Unity, MATLAB/Simulink, and Microsoft Azure Digital Twins directly support IS 2010's emphasis on experiential and systems integration learning. By lowering barriers to engagement, these kits make abstract IS concepts tangible and foster project-based learning across disciplines.

Strategies for Incorporating Digital Twins into IS curricula

Aligned with the flexible, competency-based approach of IS 2020, digital twin concepts can be incorporated into undergraduate IS programs through several complementary instructional strategies.

a) **Integrating Digital Twin Topics into Existing Curricula:**
   Digital Twin concepts can be embedded within established IS courses such as systems analysis and design, data management, enterprise systems, emerging technologies, or IT infrastructure. For instance, a DT-based laboratory might have students trace data flows between physical sensors and cloud platforms, reinforcing systems thinking and data integration competencies without requiring a standalone course.
b) **Incorporating Dedicated Digital Twin or**

Cyber-Physical System Courses:
Programs with sufficient curricular flexibility may offer elective or capstone courses focused specifically on digital twins or cyber-physical systems. These courses allow for more in-depth study of architecture, analytics, interoperability, and governance, while remaining aligned with IS 2020 competencies such as solution development, risk management, and organizational alignment.

c) **Offering Project-Based and Capstone Experiences:**
Capstone projects offer an ideal setting for DT-based learning, enabling students to design end-to-end solutions for realistic organizational problems. Examples include smart building monitoring, energy optimization, or predictive maintenance scenarios. These projects emphasize system integration, stakeholder considerations, and applied decision-making, supporting the achievement of SLO1–SLO3 in authentic, practice-oriented contexts.

Role of Digital Twin Learning Kits

Digital twin learning kits typically include low-cost hardware components (e.g., microcontrollers, sensors, actuators), software platforms, communication protocols, and visualization tools that together model key aspects of real-world systems. These kits allow students to build small-scale DT implementations that capture essential features of enterprise information systems, such as real-time data collection, digital representation, and feedback control.

These kits are designed to be accessible to students with varying technical backgrounds. Many platforms provide rapid-prototyping capabilities and visual or high-level programming environments, enabling students to focus on system behavior, integration, and decision logic rather than low-level hardware issues. As projects grow in complexity, students can incorporate analytics, security mechanisms, or cloud-based services, supporting higher-level IS competencies such as governance, scalability, and interoperability.

Within an IS curriculum, DT learning kits serve as boundary objects that bridge technical implementation and organizational analysis. Students are expected not only to construct functional systems but also to justify design choices, assess risks, and explain how DT solutions create value within enterprise environments. This combination of technical and organizational reasoning aligns closely with the goals of IS education and demonstrates the instructional potential of digital twins in undergraduate programs.

Comparative Taxonomy of Digital Twin Platforms

Digital twin platforms differ widely in cost, technical requirements, instructional affordances, and alignment with IS competencies. Understanding these differences is essential for selecting platforms that support meaningful experiential learning in undergraduate IS programs. This study organizes commonly used DT platforms into a comparative taxonomy along four dimensions:

a) Cost and Accessibility
Platforms range from low-cost, entry-level kits suitable for classroom use to more sophisticated commercial solutions. Low-cost kits enable hands-on experimentation without significant resource investment, making them accessible to programs with limited budgets. Higher-end platforms provide expanded capabilities for analytics, cloud integration, or large-scale system modeling but may require additional technical support.

b) Technical Requirements
Platforms differ in hardware and software complexity. Some kits rely on microcontrollers and modular sensors, supporting visual or high-level programming environments. Others require advanced coding, database management, or cloud configuration. Instructors should balance technical depth with student preparedness and course objectives when selecting a platform.

c) Instructional Affordances
Platforms vary in the pedagogical experiences they support. Some focus on foundational system behavior, data acquisition, and visualization, while others allow advanced exercises in system modeling, predictive analytics, or multi-platform integration. Platforms that provide modularity and scalable complexity enable instructors to design progressive learning experiences aligned with multiple student learning outcomes (SLO1–SLO3).

d) Alignment with IS Competencies
Effective platforms support both technical and organizational reasoning. Ideal platforms allow students to examine data flows, system

interactions, security considerations, and organizational impact, linking hands-on implementation to broader IS learning objectives. Alignment with IS 2020 competencies—systems thinking, data integration, solution development, and enterprise alignment—ensures that experiential exercises reinforce skills students are expected to demonstrate in professional practice.

By organizing digital twin platforms along these dimensions, educators can make informed decisions that reflect program resources, student experience, and instructional goals. The taxonomy also provides a basis for evaluating new platforms and adapting curricula as technology and pedagogy evolve.

Illustrative Digital Twin Classroom Implementation

To demonstrate the practical feasibility of the proposed instructional framework, a low-cost, replicable digital twin learning module was implemented in a classroom. The module was designed to function as an integrative learning artifact rather than a technical systems exercise, enabling students to engage with real-time sensing, data integration, visualization, and operational decision-making within a single coherent system. The instructional objective was to help students understand how physical environments, digital infrastructure, analytics, and governance mechanisms interact to support organizational decisions, consistent with the IS 2020 competency model.

The classroom digital twin focused on occupancy, space utilization, and indoor environmental conditions as a familiar and organizationally relevant context. Students worked in teams designing a small-scale cyber-physical system that collected real-time data from the physical space, routed and stored that data through an integration layer, and presented it through a spatially contextualized digital interface. Emphasis was placed on data flow, system integration, and interpretability rather than on low-level hardware configuration. This approach allowed students with diverse technical backgrounds to participate meaningfully while reinforcing IS competencies related to data management, systems thinking, and digital infrastructure.

Importantly, the instructional design emphasizes human-centered governance rather than automation alone. Students implemented transparent, rule-based operational policies that reflected organizational constraints and accountability, such as occupancy-aware resource control and threshold-based alerts. All system actions were observable and reversible, enabling discussion of trust, oversight, and ethical responsibility in digital systems. This implementation illustrates how digital twin learning activities can operationalize IS 2020 competencies in an experiential format without positioning digital twins as an engineering specialization.

By organizing digital twin platforms along these dimensions and providing examples in Table 3.1, educators can make informed decisions that match program resources, student experience, and instructional objectives. This framework also allows instructors to evaluate new platforms as technologies evolve while ensuring alignment with IS 2020 competencies and learning outcomes.

In this implementation, low-cost IoT-based platforms (e.g., microcontroller and sensor-based kits with cloud integration) were used to support real-time data acquisition and visualization. One challenge encountered was accommodating varying levels of student technical experience, particularly in configuring data pipelines and integrating hardware components. To address this, instructional scaffolding and template-based configurations were provided.

What worked particularly well was the use of real-time data streams, which significantly improved student engagement and helped reinforce systems thinking concepts. In future iterations, additional structured guidance and pre-configured modules could further reduce setup time and allow more focus on analytical and decision-making aspects. Informal student feedback indicated that hands-on interaction with live data improved understanding of system integration and increased interest in applied IS topics.

Assessment Considerations

Assessment of DT-based learning activities can be structured around project-based evaluation aligned with the defined learning objectives. Example assessment components include:

- Data integration and system functionality (e.g., correctness and completeness of data pipelines)
- System design and architecture (e.g., clarity of data flow and component interaction)
- Analytical reasoning (e.g., interpretation of system behavior and decision-making)
- Governance and security considerations

Platform / Kit	Approx. Cost	Technical Skills Required	Primary Learning Focus	IS 2020 Competencies Supported
Arduino-based Smart Home / IoT Kits	$50–$120	Basic electronics, C/C++ programming	Sensor integration, basic data acquisition, simple automation	Data & Information Management; Systems Analysis & Design
Raspberry Pi Digital Twin Starter Kits	$80–$150	Python, Linux, IoT networking	Edge computing, Linux-based services, real-time monitoring	Digital Infrastructure; Data Integration; Solution Development
MATLAB/Simulink	Academic license ($50–$100 student; higher institutional)	MATLAB coding, modeling, simulation	System modeling, simulation, predictive analysis	Analytics; Systems Thinking; Data-Driven Decision Making
Unity + IoT Sensor Integration	Free (student), add-ons vary ($0–$50)	Unity (C#), visualization, IoT data streams	Visualization, 3D modeling, interactive DT interfaces	Human-Centered Design; Solution Development
Microsoft Azure Digital Twins	Free tier; scales with usage ($0–$50/month for academic)	Cloud computing, APIs, data pipelines	Cloud-scale DT deployments, enterprise integration, IoT hub	Digital Infrastructure; Enterprise Integration; Data Management
Siemens Mindsphere Academic Tools	Institutional license (varies)	Industrial IoT, advanced analytics	Industrial DT scenarios, predictive maintenance	Enterprise Integration; Risk Management; Analytics
Node-RED + MQTT Prototyping Kits	Free software; hardware <$100	IoT protocols, data routing, event-driven programming	Middleware prototyping, automation flows, plug-and-play DTs	Systems Integration; Digital Infrastructure; Emerging Technologies

Table 3.1. Digital Twin Learning Platforms and Alignment with IS 2020 Curriculum Competencies

Note: Costs are approximate as of 2026 and may vary depending on institutional licensing, availability, and usage.

- (e.g., awareness of risks, controls, and organizational constraints)

Rubrics can be designed to evaluate both technical implementation and the ability to justify design decisions within an organizational context, consistent with IS competency-based learning.

4. EDUCATIONAL IMPLICATIONS AND FUTURE DIRECTIONS

Integrating digital twin (DT) technologies into undergraduate Information Systems curricula represents a significant opportunity to strengthen competency-based learning in the context of increasingly data-driven and cyber-physical organizational environments. By positioning digital twins as integrative learning artifacts rather than specialized engineering tools, this approach enables students to connect foundational IS domains—including data integration, systems analysis, digital infrastructure, and governance—within a unified experiential learning context. This section examines the educational implications of incorporating DT-based learning tools into IS

curricula and highlights emerging directions for advancing digital twin–enabled IS education.
A key advantage of DT learning tools is their accessibility and scalability. A range of kits—from do-it-yourself to ready-to-run solutions—is available at varying cost levels, allowing instructors to adjust activities based on institutional resources and student readiness. These tools lower barriers to complex topics, enabling students from diverse backgrounds to participate meaningfully. DT kits also support scaffolded learning: introductory exercises focus on data acquisition and visualization, while advanced projects address system integration, modeling, analytics, and security.

Digital twin activities encourage interdisciplinary engagement while remaining grounded in IS domains. Although DT systems draw on multiple technical areas, their value in IS education comes from linking technical implementation with organizational analysis, governance, and decision-making. Students are expected not only to build functional systems but also to justify design choices, assess risks, and evaluate how DT solutions deliver enterprise value. This combination reflects real-world IS practice and reinforces the systems thinking emphasized in IS 2020.

Emerging Directions in Digital Twin Education

Recent developments in DT technology offer new opportunities for IS instruction. Greater integration of IoT and sensor networks enhances the realism of DT-based learning by enabling real-time synchronization between physical and digital systems. Cloud-based DT platforms allow exploration of scalability, interoperability, and enterprise integration—central aspects of contemporary IS practice.

Advances in edge computing and analytics extend instructional possibilities by supporting near-real-time decision-making and autonomous system behavior. These capabilities can be incorporated into advanced courses or capstone projects to explore predictive maintenance, resource optimization, and resilient digital infrastructures. Immersive visualization tools, including 3D modeling and augmented or virtual reality, further support experiential and inquiry-based learning by improving system understanding and user interaction.

Importantly, the educational value of these technologies lies not in novelty but in reinforcing competency-based learning. Digital twin platforms provide opportunities to explore cybersecurity, ethical considerations, and governance challenges associated with integrated digital systems, addressing topics that are increasingly critical in IS curricula.

5. CONCLUSIONS

This paper presented a structured instructional framework for integrating digital twin education into undergraduate Information Systems programs, grounded in the IS 2010 Curriculum Guidelines and the IS 2020 Competency Model. By framing digital twins as integrative learning artifacts rather than specialized engineering systems, the proposed approach demonstrates how digital twin concepts can reinforce core IS competencies related to data integration, systems thinking, digital infrastructure, and governance.

The framework emphasizes clearly articulated learning outcomes, foundational architectural reasoning, and experiential learning supported by accessible digital twin learning kits. An illustrative classroom implementation highlights how a single digital twin learning artifact can be used to scaffold competency development across multiple levels, enabling students to engage with real-time data, system integration, and human-centered operational decision-making within an organizational context.

By aligning digital twin instruction with established IS curriculum models, this work offers a practical and transferable approach for IS educators seeking to modernize curricula without wholesale restructuring. As organizations increasingly rely on cyber-physical systems and data-driven operations, thoughtfully integrating digital twin concepts into IS education represents an important opportunity to prepare graduates for emerging professional roles while reinforcing the disciplinary identity of Information Systems education.

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