Assessing Video Game Pedagogy for Civil Engineering Education and K-12 STEM Engagement

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Introduction

Digital games have become a pervasive component of contemporary youth culture, with a growing majority of K-12 learners engaging regularly with console, computer, or mobile games. This widespread familiarity presents a significant opportunity for civil engineering educators to leverage video games as informal learning to complement their outreach and instruction efforts. Prior research in STEM education suggests that informal and experiential learning pathways – particularly that emphasize exploration, experimentation, and feedback – are especially effective for fostering interest and conceptual understanding among younger learners.

Traditional undergraduate civil engineering education largely follows a "theory-first, practice later" model, in which abstract principles are introduced in lecture and later applied in labs or design projects. While effective for advanced learners, it may inhibit K-12 students who lack exposure to engineering concepts or struggle to connect abstract theory to real-world applications. Video games can bridge this theory-application gap through their exploratory, low-stakes, and feedback-rich setting where players experiment with infrastructure systems and design/construction processes to observe consequences in real time, mirroring the engineering mindset of authentic practice. Given that these games are multimodal (combining visual, spatial, and interactive elements) they can also support diverse learning styles. These qualities position video games as a promising tool for helping students develop an early awareness that civil engineering involves systems-based, applied problem-solving to shape our built environment.

Despite this, existing literature on engineering game-based learning focuses on "serious games" custom-built for specific educational objectives with very little mention of how commercially available "entertainment games" might support early engineering thinking or identity formation. Since civil engineering is centered on spatial reasoning, system interactions, and resource constraints believed to be well-simulated by several commercial games, the authors have initiated a study to investigate their potential as pedagogical tools for outreach and instruction.

The goal of this research is to understand how video games can potentially complement traditional approaches to introducing engineering concepts, increasing engagement, and expanding access to early STEM learning. This work is defined by four objectives:

1) Evaluate the educational potential of the selected games,
2) Survey engineering students and practitioners to assess how gaming has shaped their interest in STEM pathways,
3) Conduct interviews with faculty and educators to capture perspectives on integrating game-based learning into civil engineering instruction, and
4) Develop curriculum modules for integrating games into K-12 education and outreach.

In the remainder of this paper, Phase 1 refers to preliminary efforts on Items 1-3 above. Specifically, that all the games have been subjected to evaluation by only the research team, the survey was primarily completed by students and alumni from the research team's department, and that a single faculty member in an adjacent department was interviewed. Therefore, results from this study should be understood to be exploratory rather than confirmatory with the intention of conducting more detailed, future phases of study that broaden the game evaluators as well as surveyed/interviewed individuals.

Literature Review

Prior studies on game-based learning consistently demonstrate digital games can enhance student motivation, engagement, and conceptual understanding across STEM disciplines. Generally, game-based activities improve student attitudes toward learning and support active engagement, particularly when games emphasize problem-solving, iteration, and feedback [1],[2]. Within K-12 settings, open-world and simulation-based games such as *Minecraft* have been shown to improve collaboration, creativity, digital literacy, and problem-solving skills, while supporting academic outcomes in science and mathematics when used with intentional scaffolding [3]. To that point, multiple studies emphasize that the educational effectiveness of games depends on curriculum alignment, instructor facilitation, and assessment strategies [4],[5].

Studies evaluating “serious games” for engineering education, such as bridge design simulators and construction modeling tools, indicate students’ improved conceptual understanding of structural behavior and material constraints by requiring learners to design, test, and refine solutions under realistic constraints such as cost, safety, and performance [6],[7]. They have also been found to facilitate dynamic classroom discussion, support individualized learning, and connection of abstract theory to tangible, real-world scenarios [8],[9]. Infrastructure and transportation video games are particularly effective at supporting systems thinking, as they allow students to visualize interconnected components and explore cause-and-effect relationships across technical, economic, and social dimensions, this being an essential competency in civil engineering practice [10],[11]. Beyond technical knowledge, engineering games have also been associated with increased student confidence, persistence, and willingness to engage in iterative problem-solving. This aligns with constructivist learning theories, which emphasize learning through guided exploration and reflection [12].

Despite this evidence of interest in game-based learning, there has been a decline in the development and release of STEM-focused digital educational games since 2017, particularly on mainstream distribution platforms [13]. This trend results in a need for updated guidance on how existing commercial games can be meaningfully integrated into engineering outreach and instruction. Additionally, relatively few researchers have examined how gaming experiences influence engineering identity formation, career interest, or long-term educational pathways especially within civil engineering [14]; much less, how games typically played for entertainment may implicitly communicate engineering practices, values, or professional roles. This study aims to address these gaps by systematically evaluating commercially available games and examining their potential in shaping early interest and understanding of civil engineering.

Selection of Target Games for Evaluation

The final list of nine games evaluated for Phase 1 of this study is summarized in Table 1. These were selected using five primary criteria:

1. Relevance to civil engineering concepts (broadly defined to include structural, construction, transportation, urban infrastructure, and forensic contexts);
2. Representation of engineering processes such as design iteration, constraint management, or systems interaction;
3. Engagement potential for K-12 learners;
4. Accessibility (cost, hardware requirements, and age appropriateness); and
5. Familiarity or cultural relevance based on survey responses from engineering students and practitioners.

Both *Minecraft* (educational version) [15] and the *West Point Bridge Designer* [16] can be downloaded for free from their respective websites. Licenses for all the other games were available on the online gaming platform Steam [17] between $2.50-$29.99 each.

Table 1: Video Games Evaluated in This Study

Game Title	Developer	Field	Description
Builder Simulator [18]	Live Motion Games, Frozen Way	Construction	A simulator in which players can either be guided, or tasked with relying on their own knowledge, to build homes
Cities: Skylines [19]	Colossal Order	Urban Planning	A city-building game in which the player manages and develops cities as they grow
INFRA [20]	Loiste Interactive	Forensic Engineering	The player acts as a forensic structural analyst and solves mechanical/electrical puzzles
Minecraft [15]	Mojang Studios	Construction/ Spatial Design	Players discover and extract raw materials like wood and soil, craft tools and items, as well as build structures and terrain
Poly Bridge 3 [21]	Dry Cactus	Bridge Design	A simulator in which a 2D bridge model is created and tested by the player
SimCity 3000 Unlimited [22]	EA, Maxis	Urban Planning	An open-ended city-building game in which players manage cities in real time
The Sims 4 [23]	EA, Maxis	Architectural Design	A life simulation game where the player builds and develops the in-game world with homes, facilities, and people
West Point Bridge Designer [16]	US Military Academy, Stephen Ressler	Bridge Design	An educational bridge design simulator in which players design and optimize bridges based on structural performance, material costs, and safety constraints
World of Goo 2 [24]	2D Boy	Physics-Based Design	A physics-based puzzle game where the player creates large structures using balls of goo

Note that given the timeline for Phase 1 of this study, it was necessary to constrain the list of evaluated games. However, readers may be interested in other titles identified by the survey respondents of games they had played which were indicated as relevant to civil engineering, with number of respondents listed in parentheses: *Rollercoaster Tycoon* (28), *Planet Coaster* (8), *Bridge Construction Sim* (2), *Factorio/Satisfactory* (3), *Animal Crossing* (1), *Halo Forge* (1), *Jurassic World* (1), *MySims* (1), *Restaurant Tycoon* (1), *The Farmer was Replaced* (1), *Thrillville* (1), and *Valheim* (1). The research team will plan to revisit this list in consideration for gameplay evaluation in a future phase of this study, particularly for frequently mentioned titles.

Data Collection Methods

The data collection methods described in this paper represent Phase 1 of the study on the potential for video game implementation in civil engineering outreach and instruction, associated with Project Objectives #1-3 stated previously. Three complementary methods were used in this research: (1) structured gameplay evaluation using a rubric and engagement worksheet, (2) survey of engineering students and professionals, and (3) faculty interviews. Together, these methods are meant to support triangulation across gameplay mechanics, participant perceptions, and educator perspectives.

Gameplay Evaluation Instruments

In Phase 1 of this study, gameplay was conducted by the research team to assess if game mechanics meaningfully reflect engineering practices along with numerous other game design qualities. As such, gameplay scoring reported in this paper should be interpreted as exploratory and formative with the intention of determining which of the titles and to what extent they should move forward to more detailed testing by both a larger body of engineering educators and practitioners as well as K-12 teachers and students. This would be followed with curriculum development informed by testers' feedback for pilot deployment in engineering outreach and classroom instruction settings.

To ensure a consistent and transparent evaluation of games with diverse mechanics and genres, the research team developed a gameplay rubric (see *Appendix A*). This rubric was informed by prior literature on game-based learning in engineering education as well as by recurring themes identified during preliminary gameplay. Its intent was to capture both the engineering potential of each game as well as the player experience, recognizing that effective educational tools must balance technical accuracy with engagement and accessibility. Each of the sixteen evaluation categories listed in Table 2 was scored on a five-point scale using 2-4 detailed descriptors to reduce any ambiguity and promote internal consistency.

Table 2: Gameplay Rubric Evaluation Categories

Story & Narrative	Collaboration & Teamwork	Replay Value	Pacing
Creative Freedom	Competitive Elements	Visual Design & Graphics	Sustainability
Simulation & Accuracy	Ease of Use & Controls	Sound Design	Diversity, Equity, & Inclusion (DEI)
Problem Solving & Critical Thinking	Customization	Game Balance	Overall Quality

To supplement the rubric, the research team also created a gameplay engagement worksheet (see *Appendix B*) that expanded beyond quantitative metrics by prompting written reflection on challenges encountered, technical issues, parallels to real-world engineering processes, and perceived educational takeaways in the game. These free response questions record strengths and shortcomings of the game given the goal of potential use as a civil engineering educational tool. This worksheet was also used to document total playtime, number of sessions, and the specific skills actively employed (e.g., structural design, spatial visualization, resource management, and time-based decision-making). The dual structure achieved by both the gameplay rubric and engagement worksheet supported both consistency and depth in the evaluation process.

Completion of rubric and engagement worksheet was conducted by the research team following gameplay of approximately 3-5 hours (sometimes longer). This was distributed across multiple sessions to allow sufficient time to progress beyond initial tutorials, encounter system failures or constraints, and engage in iterative problem-solving. Rubric scores reflect the judgement of the research team and meant to gauge the degree that gameplay mechanics encourage engineering-relevant thinking, support iterative design and feedback, how accurately they represent constraints and systems, and how appropriate and accessible they are for K-12 learners.

Student & Professional Survey

To capture perspectives beyond the research team's gameplay analysis, an online survey was administered to engineering students and professionals to examine how their prior video game experiences relate to their STEM interest, skill development, and perceptions of educational value. This survey captures game titles that participants indicate they played growing up relevant to the development of civil engineering skills, along with how these experiences shaped their learning, engagement, and awareness of engineering concepts over time.

Survey sections included demographic and educational background information, video game engagement and frequency, video games and educational experience, perceptions of video games in STEM and engineering education, and familiarity with specific engineering-related games. A number of the survey questions (see *Appendix C*) were intentionally structured to align with the gameplay rubric for ease of comparison. The survey was distributed through student and alumni networks associated with the research team's academic department, with particular emphasis on recruiting participants whose educational or professional experiences would allow them to reflect meaningfully on engineering learning pathways.

A total of 73 university students and professionals completed the survey. Figures 1-4 capture the distribution across: age groups (nearly split at 24 years old), gender (almost balanced, with slightly more male respondents), highest level of education (most held at least a bachelor's degree, with a substantial portion reporting graduate-level education), and work experience (though fewer had 10+ years' experience, a substantial cohort in the 5–9 year range reflects established exposure to engineering education and practice). Collectively, this demographic composition adds depth to the survey findings by grounding responses in both academic and professional perspectives with a representation across age, gender, education, and experience.

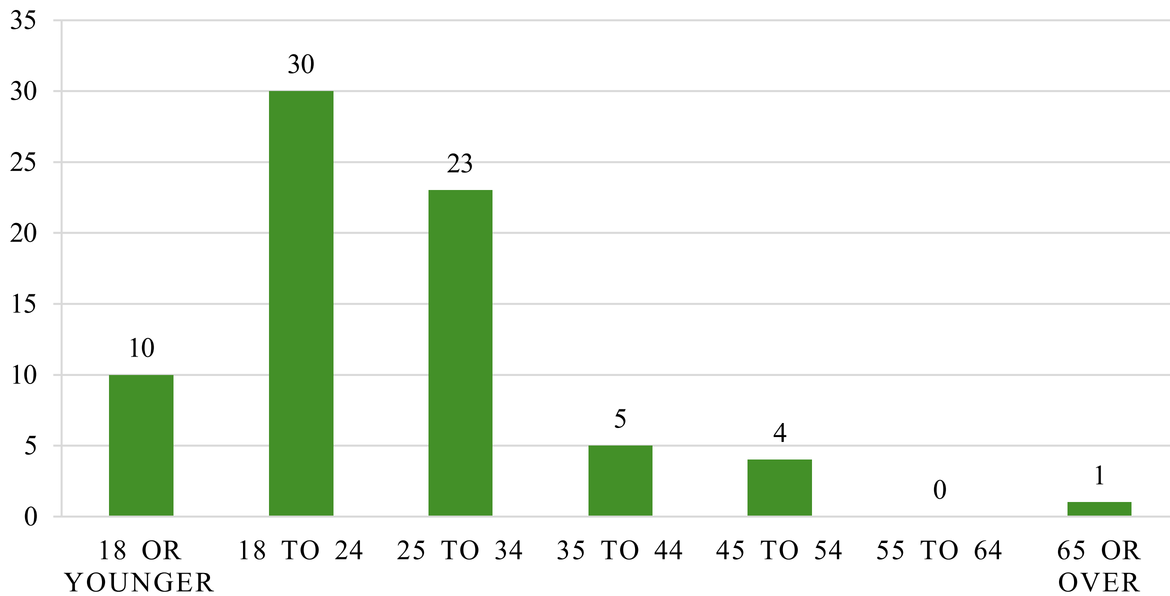

Figure 1: Age Distribution of Survey Respondents

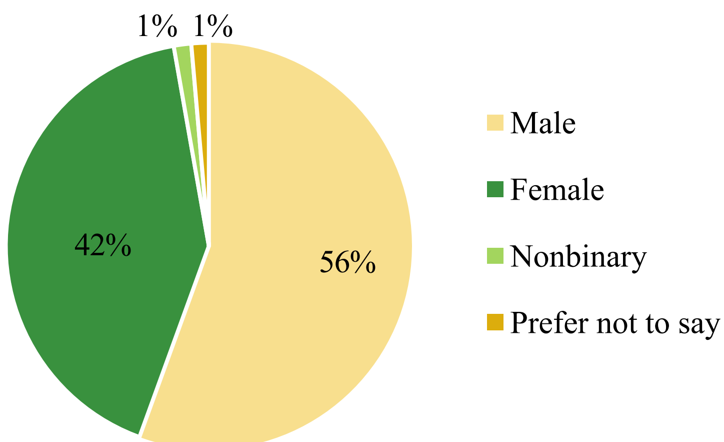

Figure 2: Gender Distribution of Survey Respondents

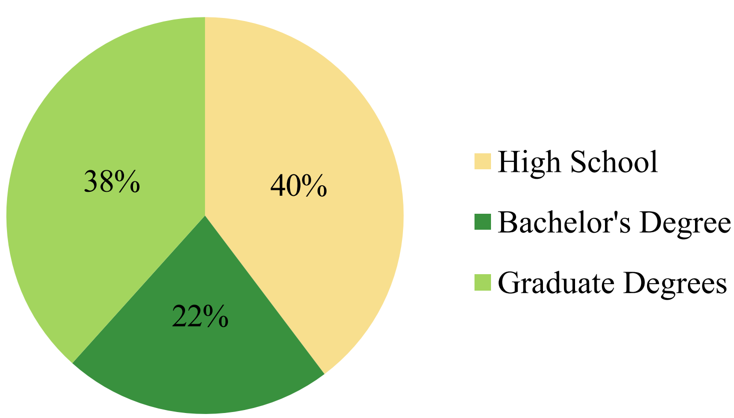

Figure 3: Highest Level of Education of Survey Respondents

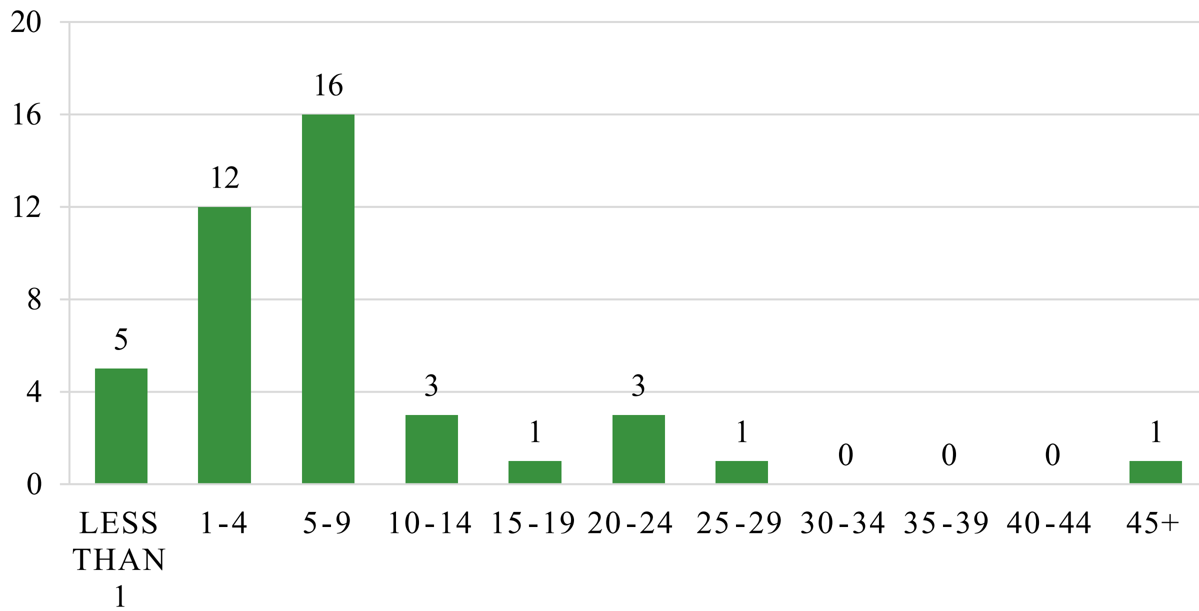

Figure 4: Full-Time Professional Experience of Survey Respondents (in Years)

Faculty Interviews

To complement the research team's gameplay evaluation and survey data collected from engineering students and professionals, they contacted several faculty members within their college that were known to have either investigated, evaluated, and/or implemented video games related to civil engineering in their past outreach and instruction. Of these, a single faculty member was available and agreed to be interviewed for Phase 1 of this study. The purpose of this in-depth interview was not to generalize across instructional contexts, but rather to provide expert insight and interpretive context regarding the pedagogical benefits and limitations of video games in engineering-related disciplines.

The interview participant was Dave Amos, PhD, AICP, a faculty member in City & Regional Planning at California Polytechnic State University in San Luis Obispo and the creator of the educational YouTube channel *City Beautiful* with over 700,000 subscribers. Dr. Amos was sought out for an interview due to his extensive experience teaching systems-oriented content to large and varied audiences, professional background in planning practice, and public facing-analysis of city-building and simulation games such as *Cities: Skylines*, *Minecraft*, and *SimCity.* His dual perspective as both an educator and experienced player positioned him well to reflect on how games function as learning tools rather than solely entertainment or technical simulations. The interview followed a semi-structured format that began with the eight pre-prepared questions (see *Appendix D*) and evolved as a conversation based on his responses. The questions used the three aforementioned city-building games as examples to discuss benefits and pitfalls of video games to teach planning/engineering concepts, effectiveness in helping develop problem-solving skills and generating career interest in young learners, as well as suggestions for how to implement these tools in K-12 outreach and education. Analysis of the interview transcript revealed several themes that aligned closely with gameplay evaluation and survey findings discussed later in this paper [25].

At the time of writing this paper, the research team is able to report on one faculty interview from Phase 1 of their study. While Dr. Amos' insights provide valuable expert context for interpreting gameplay and survey findings, they are not intended to represent a comprehensive range of educator perspectives. Future phases of this work will expand this interview component to include tailored questions that are directed at additional university instructors from other civil engineering-related disciplines as well as K-12 educators involved in STEM outreach.

Data Analysis

Gameplay Analysis

Quantitative Analysis using Gameplay Evaluation Rubric Scores

The gameplay evaluation scores assigned by the research team for the sixteen rubric categories across the nine selected games are summarized in Table 3. Cells highlighted in green identify instances where a game has an outstanding performance for the given evaluation category. This rubric scoring matrix helps identify distinctions between game genres (engineering task simulator vs. sandbox/city-building) and commonalities across all evaluated games.

Table 3: Summary of Overall Gameplay Rubric Scores Across Evaluated Games
(Maximum Score per Category = 5, Total Possible Score per Game = 80)

Gameplay Evaluation Category	Builder Sim	Cities: Skylines	INFRA	Minecraft	Poly Bridge	SimCity	The Sims 4	WP Bridge Sim	World of Goo
Story & Narrative	2	2	4	3	2	4	4	1	3
Creative Freedom	4	5	3	5	3	4	4	3	2
Simulation & Accuracy	4	4	3	2	4	4	2	5	4
Problem-Solving & Critical Thinking	2	4	4	3	4	4	2	4	5
Collaboration & Teamwork	1	1	1	4	1	1	1	1	1
Competitive Elements	1	3	1	1	5	4	1	1	3
Ease of Use & Controls	5	2	5	5	4	3	5	4	5
Customization	4	4	2	5	3	2	5	3	3
Replay Value	4	3	3	4	3	4	4	3	3
Visual Design & Graphics	5	3	5	4	4	3	3	3	4
Sound Design	3	3	4	4	3	4	5	1	4
Game Balance	3	4	2	5	4	3	5	4	4
Pacing	3	4	4	2	3	4	3	3	4
Sustainability	1	3	2	2	2	3	3	2	2
Diversity, Equity, & Inclusion (DEI)	1	2	1	2	1	3	4	1	2
Overall Quality	4	5	4	4	4	3	4	4	4
Total Score	**47**	**52**	**48**	**55**	**50**	**53**	**55**	**43**	**53**

Games that explicitly simulate engineering tasks such as *Poly Bridge* and *West Point Bridge Simulator* scored highest in simulation accuracy and structured problem-solving. These titles require players to work within defined constraints and test solutions to iteratively refine designs, closely reflecting core engineering practices. In contrast, sandbox and city-building games such as *Cities: Skylines* and *Minecraft* scored higher in creative freedom, customization and replay value, while showing greater variability in simulation realism. These games do not teach engineering concepts directly but instead foster the engineering mindset by encouraging experimentation and exploration of complex systems.

Across nearly all evaluated games, problem-solving and critical thinking emerged as consistent strengths, which align with what the engineering student/professional survey results indicate are viewed as the most important features of STEM educational games. However, gameplay evaluation scores also identified limitations prevalent across the game titles including oversimplification of engineering constraints (budget, construction timeline, and regulatory processes); potential misconceptions (ease of demolishing infrastructure or speed of system-wide changes); and limited representation of collaboration (portraying engineering work as an individual rather than a collective endeavor).

Taken together, gameplay evaluation scores suggest different game genres offer complementary educational affordances. While no single game fully represents the complexity of civil engineering practice, intentional selection and framing can allow educators to leverage each game's strengths while explicitly addressing its limitations.

Qualitative Analysis using Gameplay Engagement Worksheets

Qualitative data recorded in the gameplay engagement worksheets provided detailed insight into how learning unfolds during play and reinforced patterns observed in the quantitative rubric scores. For example, games such as *Cities: Skylines* exhibited steep learning curves, requiring sustained trial-and-error and frequent adjustment of strategies. Small planning decisions, such as road placement or zoning, often escalated into system-wide challenges, highlighting the interdependence of infrastructure systems and reinforcing systems-thinking skills. In contrast, more constrained games such as *Poly Bridge* supported focused experimentation within clearly defined problem spaces. Players engaged in repeated cycles of testing and refinement, making cause-and-effect relationships more immediately visible. Across all evaluated games, data collected through the gameplay engagement worksheets consistently documented iterative design behaviors that closely parallel engineering workflows.

The gameplay engagement worksheets also captured recurring limitations that warrant instructional attention. Several games risk reinforcing unrealistic expectations about engineering practice, including compressed timelines, simplified budgeting and the absence of policy or stakeholder constraints. Additionally, limited opportunities for collaboration were noted, particularly in games that position the player as a singular-decision maker. Overall, these worksheets provided critical context to justify games' rubric scores and how they may support or complicate civil engineering learning when used in K-12 outreach or other instruction settings.

Survey Analysis

Survey results, shown in Figure 5, indicated that video game engagement among the 73 student and professional respondents was both frequent and ongoing. Most participants reported playing video games at least weekly (68%), with a sizable portion playing several times per week or daily (54%). This suggests that respondents' perceptions are informed by current gaming habits rather than distant childhood experiences, strengthening the relevance of their feedback.

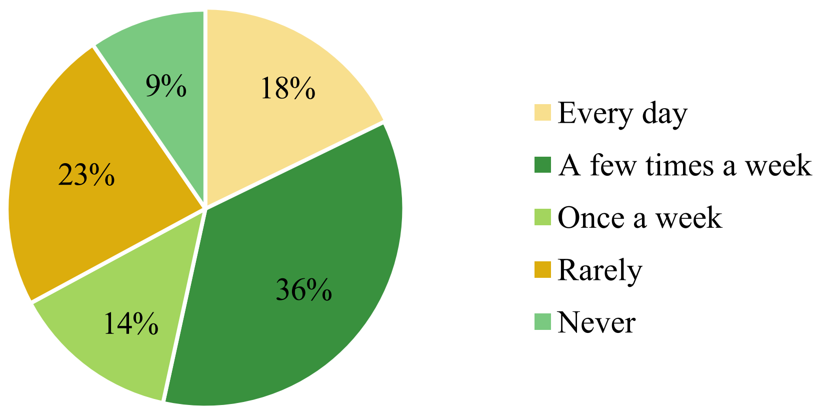

Figure 5: Frequency of Video Game Play Among Survey Respondents

Survey results related to motivations for gameplay, shown in Figure 6, indicate that respondents most frequently cited fun and entertainment, followed closely by social interaction, creativity, and problem-solving. These motivations overlap strongly with the cognitive and behavioral skills emphasized in early STEM learning, suggesting a natural alignment between gaming practices and engineering-relevant thinking. However, relatively few respondents reported playing games for school-related purposes (e.g., class or school project), highlighting a gap between gaming as a cultural activity and its intentional use in formal education.

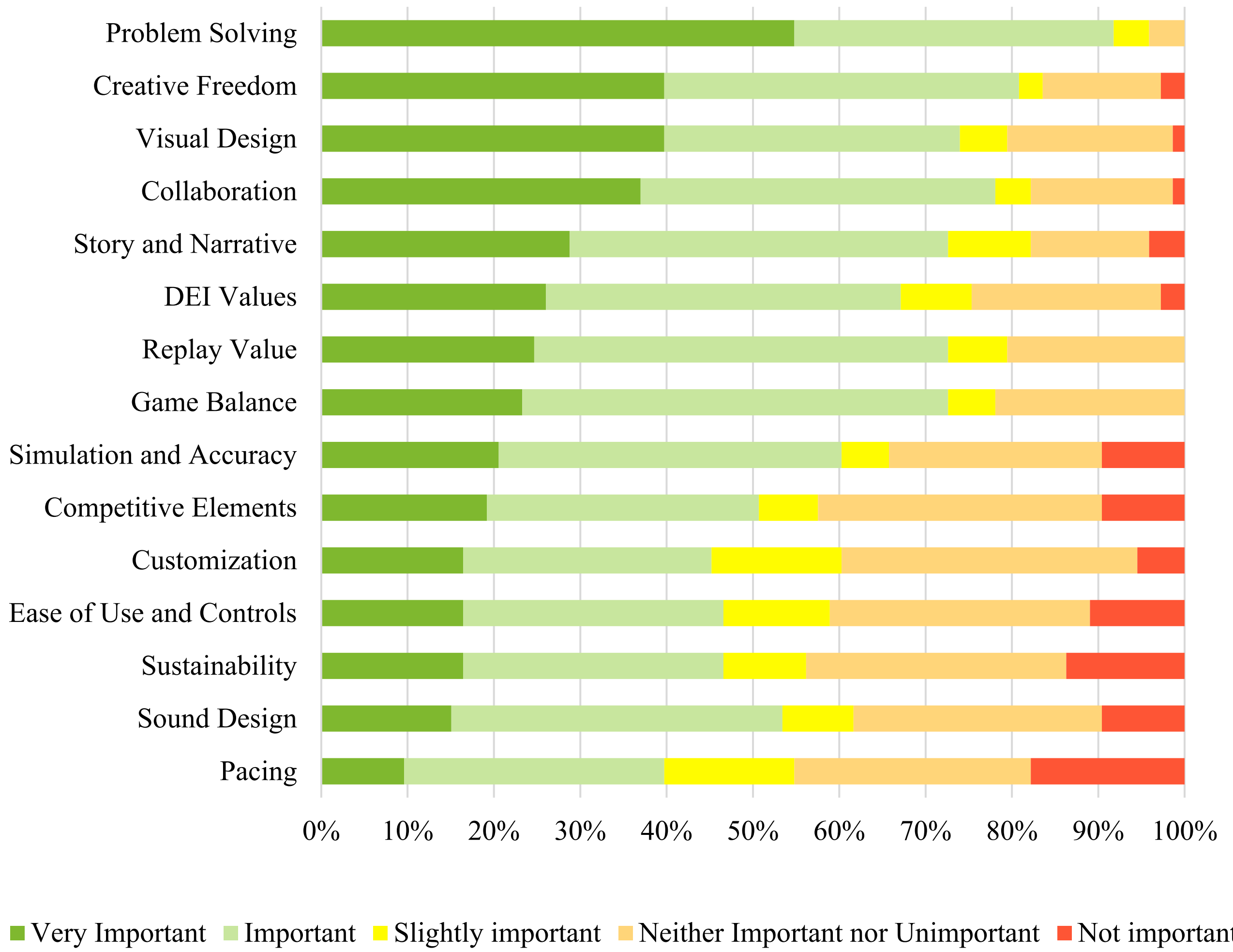

Figure 6: Primary Reasons for Playing Video Games

Survey responses revealed generally positive or neutral attitudes toward the role of video games in STEM and engineering education. Many respondents emphasized benefits such as early exposure to engineering concepts, opportunities to practice critical thinking skills, and the potential for higher engagement compared to traditional instructional methods. At the same time, respondents articulated clear caveats. Common concerns included the time commitment required for meaningful gameplay, the risk of distraction, and the oversimplification of engineering principles. Importantly, many participants stressed that video games should function as supplements rather than replacements for traditional instruction.

Participants were also asked to rate the importance of various game qualities in educational contexts, these results are shown in Figure 7. Problem-solving ranked highest, followed closely by creative freedom, visual design and simulation accuracy. Categories such as sustainability, DEI values, and customization were rated less critical overall, though still valued by many.

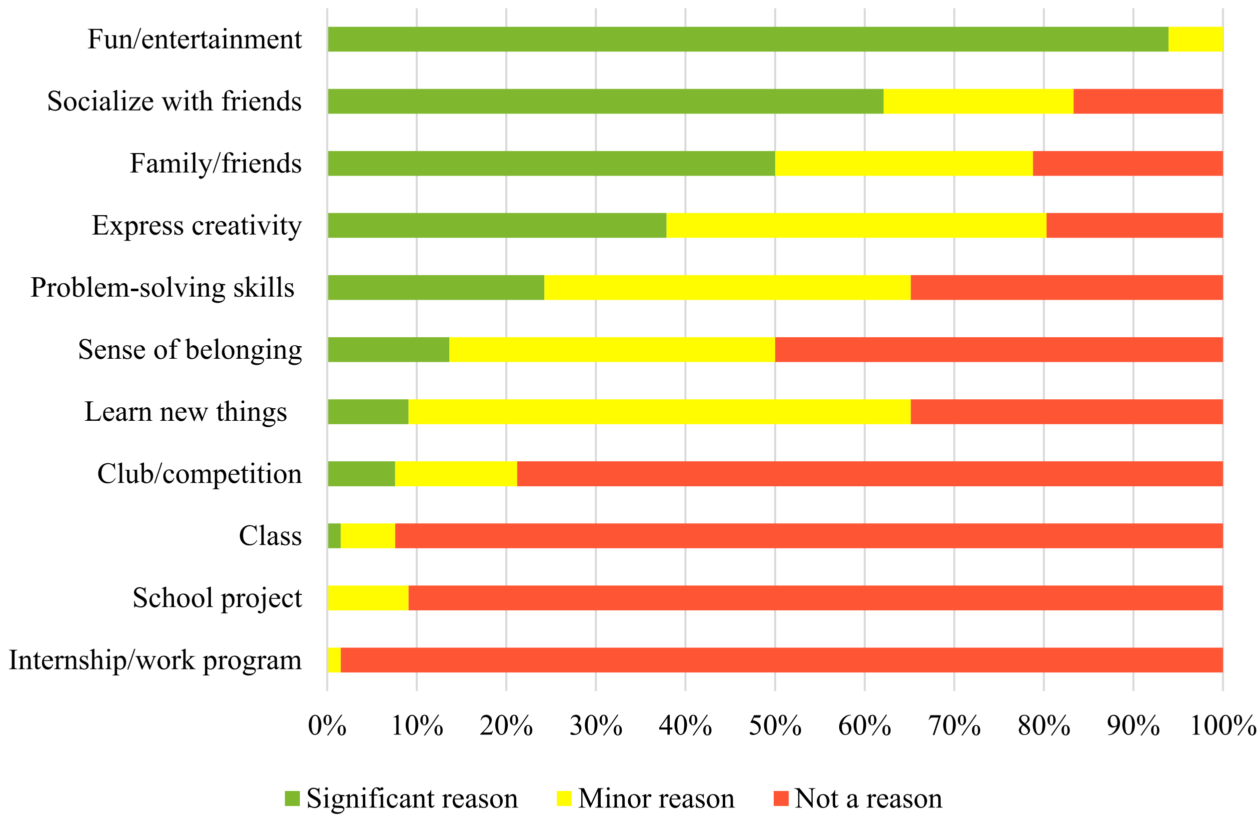

Figure 7: Importance of Gameplay Qualities in Educational Contexts

Even across demographic groups these priorities remained remarkably consistent regardless of whether responses were disaggregated by age, gender, and education level. Younger respondents did place slightly greater emphasis on creativity and visual appeal, while older participants tended to value accuracy and ease of use; however, the overarching hierarchy of priorities remained constant across subgroups.

Insights from Faculty Interviews

In his interview, Dr. Amos emphasized that city-building and sandbox games like *Cities: Skylines*, *Minecraft*, and *SimCity* are particularly effective at sparking early interest and curiosity, especially by making abstract systems visible and interactive. These games were described as valuable entry points for helping learners grasp foundational systems-thinking concepts at the K-12 level. He also distinguished between the strength of games for engagement versus instructional depth. While open-ended gameplay supports exploration and motivation, Dr. Amos stressed that consistent learning outcomes depend on structured, scenario-based activities tied to explicit objectives. Without such scaffolding, open-world games may produce highly individualized experiences that limit shared discussion or assessment. Dr. Amos also highlighted specific gameplay elements that support learning, including visual feedback mechanisms (e.g., heatmaps), trial-and-error design, and spatial reasoning through adjacency and zoning. These elements were seen as particularly effective for prompting learners to reflect on infrastructure systems that are often taken for granted.

Dr. Amos also discussed important limitations similar to those identified by the research team through gameplay evaluation. Notably, many games oversimplify professional realities of: speed of infrastructure development; ease of demolition; and absence of regulatory, political, or stakeholder constraints. Such simplifications may unintentionally reinforce misconceptions about engineering and planning practice, including that professionals operate independently or exercise unilateral control. Stemming from this, Dr. Amos emphasized the importance of explicit instructional framing and guided reflection to address these shortcomings. Rather than avoiding games with simplified mechanics, he suggested that educators can use these limitations as pedagogical opportunities, prompting students to compare in-game systems with real-world processes and to discuss where simulations align with, or diverge from, professional practice.

Discussion of Findings

Strengths of Selected Games

Across gameplay evaluation, survey responses, and faculty insights, the selected video games demonstrated strong potential to reinforce core civil engineering concepts and practices, particularly when learning is framed around exploration and iteration. Games such as *Builder Simulator*, *Poly Bridge*, and *West Point Bridge Simulator* consistently required players to design within constraints, test solutions, analyze failures, and refine approaches, which are all processes that closely parallel professional engineering workflows. While these games may differ in realism and scope, they share a common emphasis on iterative problem-solving, optimization, and cause-and-effect reasoning. These affordances align with widely recognized engineering educational competencies, suggesting that games can function as complementary environments to traditional instruction for introducing design thinking. Thus, these games can provide learners with a low-stake environment to experiment freely, fail without penalty, and revise solutions.

Several of the games demonstrate strong alignment with socio-cultural reasoning and ethical decision-making within complex systemic contexts. Even games without high simulation fidelity have been found to foster transferable reasoning relating technical decisions to societal contexts. Through sandbox and city-building games like *Cities: Skylines*, *Minecraft*, and *SimCity* players are encouraged to engage in systems thinking, spatial reasoning, and resource management and are provided in-game feedback on the broader consequences of their design decisions on virtual communities. In *Cities: Skylines*, players must interpret and respond to specific heat maps (see Figure 8a) that represent resident satisfaction with metrics such as healthcare access, pollution exposure, and proximity to parks. In *Minecraft*, players designing shared spaces must negotiate material scarcity (see Figure 8b), spatial constraints, and collaborative decision-making. In *SimCity* players are repeatedly exposed to trade-offs between economic growth, environmental quality and resident happiness forcing them to balance efficiency with public welfare. While simplified, game mechanics encourage players to consider competing priorities and the resulting stakeholder impacts, mirroring real-world trade-offs faced by civil engineers.

(a) *City: Skylines* Citizen Satisfaction Heat Map (b) *Minecraft* Material Inventory

Figure 8: Representative Gameplay Screenshots

Survey responses and gameplay observations highlight the role of games in fostering engagement and curiosity, not only individually, but also socially. As an example, during their gameplay evaluation of *INFRA*, the student researcher played in a shared living space where their roommates became interested in the narrative, and this naturally evolved into a group activity for over an hour involving discussion, observation, and informal collaboration. This spontaneous outcome – notable since INFRA is a first-person adventure game where the player acts as a structural engineer inspecting infrastructure – revealed the potential in developing group-based curriculum around the video games that support conversations about strategy, system behavior, or design choices. There is even greater potential in titles like *Minecraft*, which Dr. Amos pointed out in his interview, provides a multiplayer environment that fosters collaborative problem-solving, an aspect underrepresented in many engineering games yet essential to professional practice. Games often spark interest precisely because they are culturally familiar and socially embedded. Even when games were not explicitly collaborative in their mechanics, shared play contexts create opportunities for peer explanation, critique, and reflection, processes that mirror collaborative engineering problem-solving.

Limitations of Selected Games

Despite the strengths of selected games, there are several limitations that must be addressed for effective educational use. One recurring concern involved simulation accuracy, particularly with respect to physics and cause-and-effect relationships. While many evaluated games convey engineering concepts intuitively, the actual physics of an object is often simplified. Material behavior, loading conditions, and system response are also typically idealized for the game format. For example, structural failures in more physics-based games such as *Poly Bridge* or *World of Goo* do not fully reflect real-world failure modes, nonlinear behavior, or safety factors. Without instructional framing, learners may internalize simplified understandings that differ from professional engineering analysis. Similarly, large-scale simulation games can obscure casual relationships through abstraction. In city-building games such as *Cities: Skylines* and *SimCity*, complex interactions between infrastructure systems, environmental conditions, and population behavior are mediated through aggregated indicators and algorithmic thresholds. While these abstractions support playability and systems thinking, they may compress or mask intermediate processes, making it difficult for learners to distinguish between direct and indirect consequences of engineering decisions. As a result, cause-and-effect relationships may appear more deterministic or immediate than they are in real-world civil engineering concepts.

Unrealistic representation of time also presents a notable limitation. Many games compress planning/design, construction, and system response timelines, potentially obscuring the long-term nature of real-world engineering processes. This limitation was particularly evident in *Builder Simulator*, which emphasizes realistic construction tools and sequencing, yet condenses project timelines for playability. Tasks such as site preparation, foundation work, framing, and finishing can be completed within a single gameplay session or few discrete player actions, despite representing processes that occur over extended periods and involve multiple inspections, approvals, and coordination among trades. While this compression supports engagement and accessibility, it risks oversimplification of the temporal complexity of construction projects if used without contextual framing.

Another potential challenge of the games providing meaningful educational value is how much of the game is actually played. Some offer strong engineering-relevant lessons within a single level or scenario where core mechanics are immediately visible such as *Poly Bridge* or *World of Goo*, while large-scale simulation games like *City: Skylines* require extended playtime before meaningful systems interactions emerge. Without sufficient time or structured guidance, learners may not reach the stages of gameplay where deeper learning occurs. This limitation was also observed during gameplay of *INFRA*. Early gameplay tasks closely aligned with engineering-relevant learning objectives (e.g., inspecting infrastructure components, identifying structural deficiencies, and diagnosing issues with mechanical and electrical systems); however, as gameplay progressed, the narrative increasingly shifted toward story-driven exploration and puzzle-solving that, while engaging, became less directly connected to civil engineering concepts. This limitation underscores the importance of intentional game selection and instructional framing. A game may be well suited for educational use only within specific scopes (e.g., single scenario, constrained task, or guided session), rather than through open-ended play.

Considerations for Game Use in Educational Contexts

The findings from Phase 1 of this study suggest that video games can be effective in K-12 civil engineering outreach contexts where early exposure, curiosity-building, and accessibility are primary goals. Rather than a typical isolated outreach event comprised of brief physical demonstrations, video games provide interactive environments that allow learners to explore engineering systems over time and observe the consequences of their decisions. Games such as *Cities: Skylines* and *INFRA* are especially effective at making infrastructure systems (e.g., transportation networks, utilities, public services, and environmental systems) visible that are often obscured in everyday life. By interacting with these systems directly, students are encouraged to consider how engineering decisions affect community well-being, public safety, and environmental quality.

The study results further indicate that effective use of video games for civil engineering outreach requires that educators establish an intentional framework for selecting appropriate games and then defining a specific scope for teaching lessons within the games. Rather than evaluating games based solely on whether they are formally labeled as educational (“serious” rather than "entertainment" games) by the developer or broader academic community, educators should consider how specific gameplay mechanics align with their targeted learning objectives including technical reasoning, systems thinking, and societal impact. In this, instructors should be aware that different genres offer complementary strengths: simulation-heavy games support problem-solving and iteration within defined constraints, while sandbox and systems-based games foster exploration and broader systems awareness. Once the games have been selected, they can be leveraged most effectively for education when used as structured experiences rather than individual open-ended play. Insight from the faculty interview emphasized the value of assigning students with scenario-based tasks that focus their attention on a defined scope within the game where they address specific challenges like improving access to services or reducing environmental impacts. This approach allows educators to preserve the exploratory nature of gameplay while guiding learners toward targeted learning outcomes.

Conclusions

The first phase of the research study described in this paper explored the potential of video games to support civil engineering education and K-12 STEM engagement through a mixed-methods investigation that combined structured gameplay evaluation, engineering student and professional survey data, and an in-depth faculty interview. Findings indicate that video games can serve as effective complementary learning tools for traditional instruction, reinforcing core engineering concepts while also fostering transferable skills such as systems thinking, spatial reasoning, and iterative problem-solving.

Gameplay analysis demonstrated that different game genres afford distinct educational strengths. Simulation-focused games emphasized constraint-based design and optimization, while sandbox and systems-oriented games encouraged exploration of interconnected infrastructure systems and societal trade-offs. Notably, city-scale simulations prompted players to consider quality-of-life indicators, public services, and environmental impacts, situating engineering decisions within broader social and cultural contexts.

Survey findings reinforced these observations, with respondents consistently valuing problem-solving, creative freedom, and visual clarity as key qualities of educational games. Faculty insight further emphasized that games are particularly effective at sparking early curiosity and awareness, especially when paired with structured scenarios and guided reflection. Collectively, these findings suggest that video games can lower barriers to engagement, support experiential learning, and broaden early exposure to engineering thinking when used intentionally.

As this being the first phase of the study, this work is exploratory in nature and intended to inform subsequent research. Future phases will expand gameplay evaluation through multiple evaluators outside of the research team, incorporate additional faculty and educator interviews, and test structured curriculum modules with K-12 learners. These efforts will support a more robust assessment of learning impacts and strengthen alignment with educational standards. Future work will also explore how specific game mechanics can be mapped more explicitly to learning objectives. By refining evaluation frameworks and developing practical practitioners in integrating video games thoughtfully into engineering education.

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Appendix

A. Gameplay Rubric

Game Title: ____

Category	Score 1	2	3	4	5
Story & Narrative *Quality and immersion of plot*	☐Little to no story ☐No emotional engagement ☐Dull or incoherent	☐ Basic plot elements ☐Minimal emotional investment ☐Predictable or generic	☐Clear plot structure ☐Some compelling moments or themes	☐Strong narrative flow ☐Compelling characters and themes	☐Deep, emotional storytelling ☐Original and highly immersive
Creative Freedom *Open-ended play, player agency*	☐Linear ☐No exploration or creativity	☐Limited options ☐Few ways to deviate from the main path	☐Some player choice or branching gameplay	☐Broad player freedom ☐Customizable outcomes or approaches	☐Rich, emergent gameplay ☐High player agency and creative input
Simulation & Accuracy *Realism and logic of mechanics*	☐Game world lacks believability ☐Unrealistic or inconsistent rules ☐Misrepresents or ignores engineering mechanics	☐Occasionally unrealistic ☐Rules sometimes unclear or broken ☐Limited or unclear representation of relevant engineering mechanics	☐Mostly logical simulation ☐Rules make sense ☐Accurate representation of basic engineering mechanics	☐Consistently realistic ☐High internal logic ☐Clear and accurate depiction of engineering mechanics	☐Excellent realism and real-world accuracy ☐Consistent, believable systems ☐Exceptionally accurate and detailed depiction of engineering mechanics
Problem-Solving & Critical Thinking *Thinking through challenges in-game*	☐No puzzle or problem-solving ☐Repetitive or mindless	☐Simple choices with little thinking required ☐Minimal depth	☐Some complexity and logic ☐Moderate puzzles or planning	☐Strong strategic challenges ☐Varied types of problems	☐Complex, layered problem-solving ☐Encourages analysis and planning
Collaboration & Teamwork *Working together with real or computer-generated players*	☐No multiplayer or teamwork mechanics	☐Multiplayer available but poorly integrated ☐Few incentives to work together	☐Cooperative features exist ☐Basic encouragement to work together	☐Well-designed cooperative systems that support teamwork ☐Rewards team coordination	☐Deeply integrated collaboration ☐Team coordination is essential to success
Competitive Elements *Scoring, levels, and ranking systems*	☐No competitive design ☐No feedback on performance ☐Overly focused on competition	☐Minimal scoring or levels ☐Not motivating	☐Functional competitive features ☐Encourages improvement	☐Balanced and rewarding progression ☐Healthy competition	☐Rich and motivating structure ☐Leaderboards, ranks, or tournaments
Ease of Use & Controls *Straightforward and user-friendly design*	☐Controls unresponsive ☐Clunky or confusing interface design	☐Steep learning curve ☐Poor onboarding (tutorial)	☐Acceptable interface design ☐Mostly intuitive controls	☐Clean user interface design ☐Control easy to learn and use	☐Seamless, highly intuitive controls ☐Excellent user interface design
Customization *Personalizing characters or gameplay elements*	☐No meaningful customization options ☐Cannot change character/settings	☐Very limited customization ☐Generic feeling	☐Some character/user interface customization ☐Functional settings	☐Extensive settings and personalization ☐Enhances experience	☐Deep customization systems ☐Strong control over gameplay style
Replay Value *Willingness to replay the game*	☐No incentive to replay ☐Boring after first try	☐Some elements repeatable ☐Limited enjoyment	☐Replayable with some variations ☐Still engaging	☐Strong reason to replay ☐New challenges or experiences every time	☐Extremely engaging ☐Encourages repeated playthroughs

Visual Design & Graphics* *Style, clarity, and visual appeal*	☐Outdated or unappealing graphics ☐Inconsistent or distracting visuals ☐Visuals misrepresent or ignore engineering mechanics	☐Basic visuals ☐Limited coherence visually ☐Limited or unclear visual representation of relevant engineering mechanics	☐Clear and functional ☐Visually coherent ☐Accurate visual representation of basic engineering mechanics	☐Strong aesthetics ☐Fits game world and theme ☐Visuals clearly and accurately depict engineering mechanics	☐Visually stunning ☐Exceptional artistic quality ☐Exceptionally accurate and detailed visual depiction of engineering mechanics
Sound Design* *Engaging and atmospheric game audio*	☐Poor audio ☐Inconsistent or disruptive	☐Limited variety or low impact	☐Competent audio ☐Matches the theme	☐Sound enhances gameplay and mood	☐Deeply immersive ☐Excellent audio mixing, voice acting, and music
Game Balance *Fairness and consistency*	☐Frustratingly unfair ☐Broken mechanics ☐Rare/difficult events happen too often	☐Noticeably unbalanced ☐Difficulty spikes	☐Generally fair ☐Minor inconsistencies	☐Balanced for most players ☐Difficulty scales well	☐Expertly balanced ☐Fair across skill levels
Pacing *Flow and rhythm of gameplay*	☐Very slow or rushed ☐Repetitive or chaotic ☐Tasks/events occur far too quickly or slowly compared to real-world processes	☐Uneven ☐Long lulls or abrupt changes ☐Limited alignment with how tasks unfold in real life	☐Acceptable rhythm ☐Maintains attention ☐Moderate approximation of real-world time demands in most gameplay elements	☐Engaging throughout ☐Natural build-up and release ☐ Mostly reflects realistic timing of processes, decisions, and other engineering gameplay elements	☐Excellent pacing ☐Keeps momentum and interest high ☐Flow accurately mirrors durations found in real-world applications

Sustainability *Environmental awareness and sustainable practices*	☐No attention to environmental impact ☐Promotes unsustainable or harmful behaviors	☐Occasional inclusion of environmental themes ☐Lacks clarity or depth in sustainable messaging	☐Some in-game content promotes sustainability ☐Moderately encourages awareness of environmental issues	☐Clear emphasis on sustainable practices ☐Actively promotes ecological thinking or responsible resource use	☐Sustainability is central to gameplay or theme ☐Strong and meaningful integration of environmental values and systems
Diversity, Equity, and Inclusion *Representation, accessibility, and inclusive design*	☐No meaningful representation of diverse ideas ☐May include stereotypes or exclusionary content ☐No attention to accessibility or inclusion ☐No awareness of equity or social justice principles	☐Some diverse characters/settings, but minimal depth ☐Accessibility or inclusivity is minimal or optional ☐Limited reflection of social equity or justice issues	☐Diverse representation is present and respectful ☐Some inclusive mechanics (e.g., customizable avatars, subtitles, controls) ☐Acknowledges social equity themes in parts of the design or narrative	☐Meaningful inclusion of different identities and experiences ☐Inclusive design features are present and usable ☐Equity and justice themes are meaningfully represented in gameplay or story ☐Gameplay is accessible and welcoming to many users	☐DEI values deeply integrated into content and design ☐Exemplary representation, accessibility, and inclusivity throughout ☐Actively promotes social justice, challenges inequity, and fosters empathy ☐Game design reflects a deep understanding of engineering equity for all users
Overall Quality* *Polish, performance, and consistency*	☐Buggy or unstable ☐Poorly optimized ☐Frequent glitches or crashes	☐Occasional glitches or crashes ☐Design feels rough or inconsistent	☐Generally runs well ☐Moderate polish ☐Playable and coherent	☐Well-executed and mostly seamless experience ☐Rare bugs/disruptions ☐Strong performance and consistent polish	☐Seamless, professional polish ☐Excellent performance ☐Cohesive, immersive, and highly refined experience

*May depend on computer/internet quality

B. Gameplay Engagement Worksheet

In-Game Engagement Worksheet

Name: ________________________ Date: ________________________

Game Title: ________________________

Gameplay Engagement

How long did you play this game in total?

☐ 1-2 hours

☐ 2-3 hours

☐ 3-4 hours

☐ 4-5 hours

☐ 5 hours or more

Across how many sessions did you play this game?

☐ 1 session

☐ 2 sessions

☐ 3 sessions

☐ 4 sessions

☐ 5 or more sessions

Please check off <u>all</u> skills you found yourself actively using while playing.

☐ Structurally designing structures

☐ Applying logic or analysis techniques to a system

☐ Testing solutions and refining them

☐ Explaining or following a planned design

☐ Visualizing 3D structures and their relationship in space

☐ Aesthetically designing structures

☐ Collaboration with teammates

☐ Resource management

☐ Time management (i.e. task prioritization, construction and maintenance scheduling, production timing)

☐ Monetary management

What age group would you say this game is intended for? (select all that apply)

☐ Young Children (7–10 years)

☐ Tweens/Preteens (11–13 years)

☐ Teenagers (14–17 years)

☐ Adults (18+)

Please rate the following aspects and how they apply to this game. Use the given rubric to help guide your ratings for each category.

	1	2	3	4	5
Story & Narrative	☐	☐	☐	☐	☐
Creative Freedom	☐	☐	☐	☐	☐
Simulation & Accuracy	☐	☐	☐	☐	☐
Problem-Solving & Critical Thinking	☐	☐	☐	☐	☐
Collaboration & Teamwork	☐	☐	☐	☐	☐
Competitive Elements	☐	☐	☐	☐	☐
Ease of Use & Controls	☐	☐	☐	☐	☐
Customization	☐	☐	☐	☐	☐
Replay Value	☐	☐	☐	☐	☐
Visual Design & Graphics	☐	☐	☐	☐	☐
Sound Design	☐	☐	☐	☐	☐
Game Balance	☐	☐	☐	☐	☐
Pacing	☐	☐	☐	☐	☐
Sustainability	☐	☐	☐	☐	☐
Diversity, Equity, and Inclusion	☐	☐	☐	☐	☐
Overall Quality	☐	☐	☐	☐	☐

Educational Gameplay Analysis

Wtlat did you enjoy most about the game?

Describe one or two notable struggles you encountered during gameplay.

Did you experience any lag or technical issues during gameplay?

What parallels, if any, did you notice between gameplay mechanics and real-world engineering processes?

In your opinion, what are the most valuable educational takeaways from this game?

Wllat limitations, if any, do you see in using this game as a learning or teaching tool?

What is an educational module you would create that implements this game? Please include the estimated time to complete the module, a plan for what students would do in-game, and any hands-on components (i.e. writing, drawing, or physical model).

C. Summary of Student & Professional Survey Questions

I. Demographic/Background Information

- Gender, Age, Racial/Ethnic Group
- Highest level of education completed
- If undergraduate completed: academic degrees (school, degree, year awarded)
- Discipline, education/work status, and years of employment
- If professional: engineering licensure status, other relevant licensure/certifications held
- If professional: employer and current job title

II. Video Game Engagement

- How often, if ever, do you play video games?
- Have you ever been interested in trying video games, but chose not to? (Follow ups: What made you consider it? What has kept you from trying video games?)
- Rate to what extent the following is/was a reason you play video games (3-point scale):
  Learning new things
  Developing problem-solving skills
  Socializing with friends
  Because of friends/family
  For a club/competition
  For a project (school or otherwise)
  For a class (K-12 or other)
  For an internship/work program
  To express creativity
  For a sense of belonging/identity
  For fun/entertainment
- Have you ever observed other playing video games…
  On Twitch
  On YouTube
  On Facebook
  At home (friends/family)
  If you selected any of the above, did anything about these experiences stand out to you?
- Rate how much the following played a part in your decision to go into engineering (5-point scale):
  Video games
  A TV show/movie
  Hands-on activity
  A specific book/book series/author
  Strong interest in math/science
  Family members/friends in the field
  A magazine
  A podcast
  Online content
  A specific media personality
  Elaborate on or provide an alternative answer to responses.

III. Video Games and Educational Experience

- Have you ever played video games as part of a school-related activity, such as a class, project, club, or competition? (Yes/No)
- Select any applicable options of where/when you played video games, primarily for educational purposes.
  Pre-K
  Elementary School
  Middle School
  High School
  Club or other extracurriculars/competitions
  At home (through parents or independently)
  Other (could specify)
- If you played video games as part of a competition, what competition was it for?

IV. Perception of Video Games in Education and STEM

- What are your general perceptions of video games and their role in education or learning?
- How important are the following qualities to you in a computer or console video game, especially in an educational or STEM-related context? (5-point scale)

Engaging storyline or narrative	Customization and user control
Creative freedom or open-ended play	Visual design and graphics
Realistic simulations or accuracy	Replay value (fun to play more than once)
Problem-solving and critical thinking	Sound design
Collaboration or teamwork features	Flow and rhythm of gameplay
Competitive elements	Environmental awareness/sustainability
Ease of use and intuitive controls	Fairness and consistency
Representation, accessibility, and inclusive design	

- Do you believe video games could have educational value in STEM or engineering? Why or why not? Please include any benefits, potential drawbacks, or limitations.
- Do you have any suggestions on how you would like STEM/engineering video games to be represented in K-12 and undergraduate education?

V. Familiarity with Specific Games

- What structural engineering-related console/computer games have you played?

Builder Simulator	Rollercoaster Tycoon
Cities: Skylines	SimCity
INFRA	The Sims
Minecraft	World of Goo
Planet Coaster	West Point Bridge Designer
Poly Bridge	Other (Could specify)

D. Faculty Interview Questions – Prepared for Dr. Dave Amos

1. From your perspective, what unique value do games like SimCity, Cities: Skylines, or Minecraft bring to teaching planning or engineering concepts?
2. Do you think these games are most useful for sparking interest in STEM/CRP fields, or for developing broader skills like systems thinking and problem-solving?
3. Have you seen examples where K–12 teachers have successfully integrated city-building or construction games into their classrooms? What seemed to work well (or not so well)?
4. What specific elements of gameplay do you think translate best into effective learning experiences for K–12 students? (e.g., visual feedback, trial-and-error design, resource management)
5. How might educators structure activities around these games so that play leads to meaningful engagement with planning or engineering concepts, rather than just entertainment?
6. What misconceptions about planning or engineering do these games risk reinforcing for K–12 learners, and how might educators address them?
7. From your perspective, how do you think games shape how young people imagine the role of planners and engineers in society?
8. Is there any advice you would give me as I build the case for the credibility of games in K–12 pedagogy, especially when addressing skepticism from educators or academics?