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Characteristics of Authentic Construction Learning Experiences to Enable Accurate Consideration of Cost-effective Alternatives

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Abstract: Authentic learning opportunities that simulate full scale design and construction experiences using real materials offer ideal experiential learning environments for construction and civil engineering students by challenging students to apply building concepts in practical settings. However, the excessive cost of real building materials required for this mode of education limits access to the vast majority of students. As a result, educational researchers have explored potential alternatives to provide cost-effective experiential learning through activities using mock-up materials (e.g., plastic straws, popsicle sticks) and simulation of experiences using immersive technologies (e.g., virtual reality or augmented reality). While some of these alternatives approximate the environment and others provide physical interaction with mock-up materials, the lack of authenticity in the building materials used introduces some apparent differences between the "authentic" learning environments and their cost-effective approximations. Therefore, this research aims to identify the learning processes reported by students and faculty who participated in authentic learning experiences to understand the ways in which this mode of education offers unique value to construction education. Their interview responses illustrated characteristics of authentic learning experiences that were believed to be critical to the learning process, some of which included: working in groups; interdisciplinary participants; and use of real construction materials. Although some of these characteristics are intrinsically linked to the use of real materials, others do not explicitly refer to interaction with real materials. This may indicate to aspects of the authentic learning processes that educational researchers can strategically target through more cost-effective learning environments like virtual and augmented reality. The contribution of this paper is in identifying the characteristics of authentic learning experiences that may guide educational investment and research innovations that aim to replicate some of these learning experiences through more accessible learning environments.

Keywords: authentic learning; experiential learning; real materials; immersive technologies; virtual reality; augmented reality

1. Introduction

Construction professionals rarely build identical structures with identical project teams, requiring them to take advantage of their experience to make decisions that are appropriate to the specific needs of a particular project and team. This highlights the need for Architecture, Engineering and Construction (AEC) students to apply theoretical concepts to practical applications to be ready for career success [1–3]. This form of learning that is facilitated by experience has been established in the education literature through notable work on experiential learning theory (ELT) by prior researchers [4–7]. Therefore, in response to various sources reporting the value of hands-on experiences [8–11], educators have leveraged experiential learning activities where students are challenged to apply theoretical concepts to the design and construction of a physical structure.

In this effort to provide experiential learning, educators have incorporated activities involving physical design and construction to apply theoretical concepts to the design and construction of a physical structure [1]. However, learning experiences that use real building materials and in an actual setting (referred to as authentic activities in this paper) remain inaccessible to the majority of students due to the high costs associated with this mode of learning [12]. The high costs of conducting these activities have also constrained the research output regarding this specific mode of education. Therefore, while there are experiential learning opportunities through authentic activities, there has been a need for alternative cost-effective alternatives to provide similar learning gains.

In order to avoid excessive costs attached to conducting authentic activities using real construction materials (i.e. authentic materials like concrete, lumber), most studies on experiential learning are conducted indoors using mock-up materials (e.g., cardboard, plastic straws) or virtual models [13–15]. While the mock-up materials afford physical interaction with materials during learning, they do not simulate a realistic setting of a construction project. On the other hand, while virtual models do not allow for physical interaction with materials, there is potential to simulate a realistic virtual environment that mimics a real construction site. These accessible modes of education offer promise, but often do not make claims about their learning value compared to truly authentic learning (real materials and actual setting) because the cost of doing so would be prohibitive. A more thorough understanding of the learning experience reported by participants of authentic learning would allow researchers to more directly compare reports of learning with these alternate methods to reports from students who participate in the more resource- intensive authentic learning modes. This paper aims to identify aspects of authentic learning experiences that facilitate learning to inform the importance of the activity's authenticity and consequently to evaluate cost-effective alternatives.

2. Background

Active and experiential learning have been studied extensively by educational researchers [16–19] and there are several types of active learning that educators can adopt. While there is a large body of existing research on active learning, the specific meaning of 'active' in this literature is obfuscated by various interpretations of active learning among educational researchers [20]. Not all interpretations involve the use of real materials in the learning process. As a result, the authors of this work cannot automatically leverage all active learning reports in the literature based only on a search using similar keywords (i.e., "active", "experiential", or "hands-on" learning). Therefore, even though experiential and active learning to have been studied extensively, the body of literature on authentic learning is much smaller — especially as it relates to construction education.

In the limited existing literature that report learnings specifically from authentic activities, a number of learning gains have been attributed to them such as decision- making [21,22], collaboration [23–25], critical thinking [21,24] and leadership [25,26]. To enable such learning gains through the exploration of cost-effective alternatives there has been some research that suggests technologies like virtual models and the use of mock-up materials which significantly reduce the resources required to provide the learning expe- rience [13–15,27]. In a comparison between using virtual model and mock-up materials, no difference in performance was seen, suggesting the potential for virtual versions of a learning activity to replace physical materials, effectively reducing the costs of replicating and duplicating the activity and also reducing logistical burden by reducing of space and effort requirements [13]. However, there is also evidence that some amount of physical manipulation was still important to improve learning among children for

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basic physics principles [28]. More importantly, while these studies address the role of physical inter- action with materials in the learning process, they do not specifically study and isolate aspects of the activity that may have impacted the learning gains.

Due to the limited research outputs from actual authentic activities (i.e., full scale design and construction learning to use real materials), the role of authenticity and thereby its specific benefits have not been thoroughly explored. Furthermore, among the studies that report on activities that use authentic materials, the reports are often contextualized to the goals of the particular activity and are not always focused on understanding the learning processes of participants relevant to construction education. Therefore, the aspects of authentic activities that led to those learning are not known.

Due to the high value of authentic activities, but low presence of findings related to it, educational researchers interested in all types of experiential learning would be supported through a better understanding of what aspects of an authentic learning experience facilitate desired learning outcomes. In this study, interviewing participants of authentic learning experiences will enable researchers to understand what aspects of their experiences are perceived to be instrumental to their learning. Also, since using real materials constitutes a significant portion of the cost of an authentic activity, the researchers used a deductive approach in specifically inquiring the role of physical materials in the learning experience reported by participants. This understanding may help to guide future investment in authentic learning and suggest opportunities for exploration of inexpensive, but potentially effective, alternative learning environments to broaden access to learning. Therefore, this paper addresses the following research question:

- RQ: What are the characteristics of authentic learning activities reported by participating students and faculty that facilitate learning outcomes?
- RQ: In what ways do respondents indicate the role of physical materials in supporting their learning experiences?

3. Methodology

The methodology of this paper involved conducting semi-structured interviews with participants of authentic learning experiences. These interviews were intended to provide an in-depth understanding of specific aspects of the experience that may have led to the learning outcomes experienced by the participants.

3.1. Interview Protocols

A semi-structured format was used as the interview approach. In this format, every participant is asked similar questions, while being careful in wording the question to elicit an open-ended response [29]. This open-endedness allows respondents to fully express their experience and researchers to get detailed information with probing follow-up questions. In the scope of this work, whenever an interviewee mentioned a learning outcome, the interviewer would follow-up with a question to determine what about the activity was believed to lead to that particular learning outcome. This process added a contextual understanding to the reports of the participants which allowed the authors to better understand the characteristics of the activity that played a potentially essential role in the learning process. Following are some open-ended questions that the researchers used to guide the semi-structured interviews:

- How was your experience participating in the activity?
- How was the activity beneficial to you/your students?
- If any, how did this activity help in developing a specific skill?
- If any, what led to new insights into the construction process?

3.2. Selecting Interview Participants

The participants interviewed for this study consisted of both students and faculty members who had previously participated in one or more authentic learning activities. Adopting a phenomenological epistemology, both student and faculty members were recruited to get a comprehensive representation of the experience of an authentic learning activity [30,31]. This enabled the authors to consider not only the student's perspective of their own experience but also that of the faculty who had an outsider's objective perspective on their students' learning gains. To be selected, the activity had to be an authentic activity, which meant it had to involve the use of actual construction materials with which the participants physically interacted in real construction project circumstances. For example, if an activity utilized plastic straws as building materials, or if it only involved observing a construction site, but not actually building any components, it would not be included in this study. The authors identified a sample of participants by contacting faculty and students from their home university and participating universities listed on hands-on competition websites. This strategy enabled the authors to identify individuals with authentic learning experiences within and beyond their own institutions.

3.3. Data Collection

This study adopts a constructivist paradigm, allowing for knowledge to be co-constructed between the researcher and participants. More specifically, the interviews conducted in this study allow for the construction of rich, contextualized data from the participants' experiences that lead to an in-depth exploration of the phenomenon. The interviews aimed to gain insight into the beneficial characteristics of authentic learning activities through individual perspectives of participants who had first-hand experience with them which is especially valuable in this specific area of research where there is limited literature.

The interviews were conducted either face-to-face or via a video conferencing application depending on the convenience of the interviewee. Due to open-ended responses, the duration of the interview length depended on the amount of detail the interviewee chose to provide and the number of follow-up questions that were asked. Both the student and faculty interviews were audio-recorded when conducted in person. In situations where the interview was conducted remotely, the video calling session was recorded. In either case, the interview transcripts allowed the authors to revisit portions of the interview dialogues, when necessary, to confirm previous assumptions or deduce new themes within the participants' comments during the analysis portion of the investigation.

3.4. Data Analysis

The transcripts of both student and faculty interviews were analyzed as a single group at a semantic level using thematic analysis where the themes, or characteristics of authentic activities in this case, were identified within the explicit meanings of the data without any further investigation of what a participant said [32]. The data analysis process was similar to other interview analysis protocols conducted in previously published engineering education research [33,34]. Learning outcomes reported in existing literature on experiential learning in AEC [10,22–26,35,36] were used as framework to code the transcripts based on established learning outcomes expected from this mode of learning. Organizing the findings in this manner helped to associate known learning outcomes with the themes that emerged, highlighting potential characteristics of the experience that facilitated those outcomes.

Next, in order to deduce which of the reported learning gains were the result of characteristics exclusive to authentic learning activities and which may not have been intrinsically linked to the activity, the authors recursively analyzed the coded learning outcomes in context of the characteristics that participants stated facilitated those learnings. For example, keywords that characterized the nature of the activity, such as 'teamwork', 'interdisciplinary interaction' and 'time constraints', began to emerge in responses to follow-

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up questions that inquired what about the activity led to particular learning gains. The authors then re-explored the collected data from all participants. When participants mentioned a specific learning gain, the authors checked to see whether they had also mentioned one of the keywords, or a synonymous term, during their description of this learning gain. If they did, the learning gain reported was categorized based on this keyword. In this manner associations were established, based on participant perceptions, between a certain coded learning outcome and characteristics of the authentic activity that may have been critical in facilitating the learning process.

To further illustrate how this methodology was implemented, an example is provided here. The characteristic of ‘working in groups’ (theme) emerged as a characteristic of authentic experiences regarded as beneficial in facilitating learning gains such as accountability, leadership, and collaboration (codes), which were deduced from transcripts of the conducted interviews (raw data). Thus, from the reports of participants of authentic activities, an association was established between this characteristic of the experience and the learning gains mentioned in the literature on hands-on learning. In instances when learning gains could be associated with multiple emergent characteristics, the reported gains were associated with all characteristics mentioned by the respondents to avoid incorrectly assuming one characteristic over another during analysis. Ultimately, this approach allowed the authors to make sense of their unstructured findings to inform broader conclusions about the perceptions reported by student and faculty authentic learning participants.

4. Results

In total, twelve individuals were interviewed, including seven faculty members and five students. Figure 1 illustrates the variety of authentic learning activities in which the interviewees participated. Of these, four were unrelated to students’ coursework and were extracurricular events facilitated by organizations like the American concrete institute (ACI), the American society of civil engineers (ASCE) and the Department of energy (DOE). The fifth category included authentic learning activities that were conducted as part of coursework outside the classroom and involved hands-on learning similar to the extracurricular activities explored. The following are short descriptions for each activity:

- *Solar Decathlon:* Competition to design and build high-performance, low-carbon buildings
- *The Tiny House Competition*: Competition to design and build tiny homes
- *ASCE competitions:* Competitions organized by ASCE to provide hands-on experience
- *ACI’s operation Ramp-Up:* Event to support veterans by building or renovating concrete
- ramps *Coursework:* Hand-on design experience included in architecture and construction coursework

Among the interviewees, the faculty members had been involved in authentic experiences at least two times in their teaching careers. All the students interviewed were either upperclassmen or graduate students. All experiences involved real construction materials and physical interaction with the materials by the participating students.

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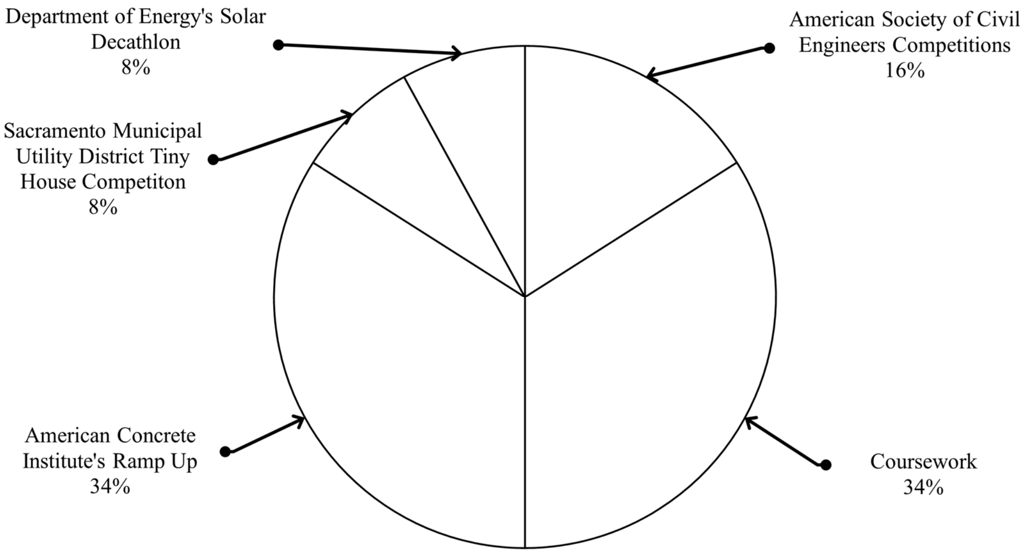

Figure 1. Distribution of Interview Participants.

4.1. Instrumental characteristics of authentic experiences

After the interviewees indicated which aspects of learning they believed were enhanced through the authentic experience, they were also asked what they perceived to be the cause(s) of the learnings they reported. This enabled the authors to discover specific characteristics of the authentic learning experience that were believed to be associated with the learning gains. More specifically, these identified characteristics of the authentic experience that emerged through the transcripts helped to illustrate which of the reported learning outcomes were perceived to be linked to various aspects of the activity by participants. These characteristics and learnings associated with them are shown in Table 1. In order to present the results in a usable manner for future researchers interested in replicating specific aspects of an authentic learning experience, the findings are organized according to the characteristics that emerged during interviews, which are briefly discussed in the following sections:

Table 1. Characteristics and associated learning outcomes.

Excerpts from transcripts (*Raw data*)	**Learning Outcomes (*Initial codes*)**	**Characteristics (*Themes*)**
Process of building formwork	Problem solving	**Engagement in construction processes**
Constructing wooden bench	Construction	
Determining alternate construction activities when delays occur	Sequencing Decision making	
Cane clearance recognition for blind user	Empathy for user	
"You are forced to work as one to succeed"	Collaboration	**Working in groups**
"The over committed motivate the under committed"	Motivation	
"Nobody wants to fail and come on the radar"	Accountability	
Students form roles within groups to reach a goal	Leadership	
Construction and Architecture students roleplaying project relationships	Collaboration	**Interdisciplinary participants**
Students must communicate with professionals from other industries for material delivery, design reviews, and constructability feedback	Motivation Interdisciplinary negotiation	
"Concrete finishing is an art that you need to feel	Material behavior	**Use of real**

Assembling premade elements of wooden bench when joint connections had to be made	Construction sequencing	**construction materials**
"When time has consequences, students are urged to think clearly and solve problems"	Critical thinking Decision making	**Time Constraint**

4.1.1. Engagement in construction processes

This characteristic meant that participants had the opportunity to participate, visualize and contribute to a construction process as an active member. This aspect of authentic experiences was recognized as a pattern when interviewees referred to a particular process, such as finishing concrete, building formwork, or other construction-related processes. As an example, during an interview, a student participant reported 'problem solving' as a learning outcome and referred to discovering then when they experienced how many complexities go into putting formwork together. The participant emphasized how they had not realized the level of difficulty until actually building formwork during their authentic experience through American Concrete Institute's ramp-up event.

4.1.2. Working in groups

The aspect of working in groups was common to all authentic experiences in which students had to work with team members to achieve a common goal. Participants usually referred to this characteristic by mentioning how challenging working in a group was, but added that it was instrumental in the development of certain skills. Referring to this challenge a faculty member said, "You are forced to work as one to succeed and nobody wants to fail and come on the radar". It was also recognized by faculty interviewees how working in groups is a major part of what construction professionals must do in their careers. The same types of experiences related to working with individuals with different backgrounds that were observed in the academic environment are also likely to be present throughout students' construction careers.

4.1.3. Exposure to interdisciplinary participants

This characteristic emerged as interviewees discussed the impact of working with individuals with different areas of expertise on the same project. An example of this in the Solar Decathlon was student groups composed of architecture students, civil engineering students, and construction management students. A faculty interviewee stated that construction and architecture students working together is beneficial because this role-playing gives them a better understanding of the dynamic that exists on real projects between different stakeholders. In some activities, this exposure came in the form of interacting with real professionals from other disciplines where students needed to coordinate with real vendors to complete the activity. A faculty interviewee emphasized the importance of this exposure as students might otherwise rarely encounter professionals from other disciplines, since faculty members and their students tend to be from the same discipline.

This opportunity to interact with interdisciplinary students and professionals is a unique opportunity to gain understanding of the various working relationships on a construction project.

4.1.4. Use of real construction materials

This characteristic highlights the specific benefits reported from the use of real construction materials. Some interviewees considered it impossible to understand the way certain materials behave under varying conditions without actually interacting with those materials. As an example, an interviewee mentioned how concrete changes its properties during the finishing process and insisted this is difficult to appreciate without physically working with concrete. One faculty participant stated, "Concrete finishing is an art that you need to feel to understand." Another faculty member encouraged the use of real materials in learning experiences, arguing this helped students understand the functions of building elements better.

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4.1.5. Time constraint

The time constraint characteristic meant the goal that student groups were working toward had a time limit for completion. A faculty interviewee expressed how the time constraint was crucial for putting students in situations where successful groups were forced into thinking critically and making decisions. This faculty member also noted this was a good simulation of real-world projects as there are real consequences to missing deadlines, which are not always present in classroom activities.

5. Discussion

The characteristics listed in Table 1 provide context to the learning process that occurs during authentic construction experiences and give insight into aspects of the experiences that the participating members report as important in facilitating the learning outcomes. These characteristics in turn enable future researchers to identify the ways in which cost-effective alternatives may provide similar learning experiences to authentic learning activities.

Among the characteristics of authentic activities that emerged, it should be noted that only a few of the responses from the participants explicitly linked the interaction with real construction materials with coded learning gains. More interestingly, none of the responses specifically attributed their learning experience specifically to the authenticity of the environment. The authors had expected that more responses would directly reference learning from interaction real materials, especially when considering the costs required to provide this rare experience to students. To be clear, the authors do not suggest that this evidence means that interaction with physical materials is not important. Instead, the findings suggest an opportunity for additional exploration into more cost-effective alternatives to support many of the learning gains with fewer resources. For example, future researchers may continue using mock-up materials, but with the aim of targeting specific characteristics from this work that were not explicitly linked to interactions with materials. Similarly, for situations where students need to learn how project-wide decision-making impacts specific construction processes, but firsthand experience in (for example) carpentry tasks may go beyond what would be expected of management students, educational researchers may explore simulations to in a virtual environment to convey the relationships between specific work tasks and broader decision-making. While the findings from this paper cannot directly make claims about the extent to which approximations of authentic learning can offer value, the findings can guide what forms of educational value are targeted by future research.

In addition to guiding future studies on more affordable forms of experiential learning, the findings also highlight some learning gains for which physical interaction is perceived to be required, which may provide evidence to justify investment in authentic experiences for certain situations. Learning outcomes that were attributed to the use of real materials immediately emerge as an instance that might be difficult to replicate without real materials. Interviewees indicated that interactions with materials facilitated understanding of material behavior and construction sequencing. This seems logical as physical interaction with the material, quite literally, requires students to observe or otherwise experience material properties as they build. This understanding of the specific benefits reported from authentic learning can help educators prioritize their investments in authentic learning in contexts that have direct evidence of value for learning.

The characteristics of authentic learning defined in this work suggest opportunities for future research to strategically explore both authentic learning and also inexpensive approximations to replicate experiences reported from participants. However, this does not mean that educators should assume that the success of mock-up materials, simulations, or other inexpensive alternatives suggests the ability to fully replace authentic learning. Potential synergies between the characteristics reported may not be present when targeted in isolation, which may impact the value they provide to students. For example, prior research has reported many of the learning gains observed in this work through less-expensive means: [37] reported increased motivation; and [38] and [39] reported improved collaboration through virtual environments. However, it is possible that the isolated nature of their implementation had an impact on the reported learning gains, whereas authentic experiences facilitate learning gains in aggregate during a single experience. It is possible that the effort employed by students in authentic experiences to (for example) work with others from different disciplines is greater because ramifications associated with poor interoperability will be more impactful in the eventual real construction process than in processes that are only approximated with mock-up materials. Therefore, in addition to targeting aspects of authentic learning with more accessible modes of education, future researchers should explore the ways in which cost-effective learning alternatives may support aspects of authentic learning in aggregate in order to better understand the opportunities, but also limitations, associated with replicating authentic learning in cost-effective environments.

5.1. Potential for cost-effective learning through virtual environments

In response to the need to provide realistic learning environments, like those enabled by authentic activities, educational researchers have been exploring the use of immersive virtual environments to replicate these types of experiences cost-effectively. While immersive technologies like Augmented (AR) and virtual reality (VR) require upfront resources to develop the virtual experience aimed at specific types of learning, they may be scaled more effectively as they do not require new physical materials for all students. Instead, a single AR/VR device may be reused by multiple students and once developed, the virtual experience can be deployed on multiple devices at the same time. At this scale, a major saving over truly authentic learning may be possible.

Virtual experiences through AR/VR have already been proven to be effective in other industries by improving psychomotor skills [40–42] and within construction education contexts [43] to support students' abilities to generate and effectively communicate constructability review feedback before construction [44–46] and to monitor and identify hazardous conditions on a construction site [47–49]. These prior studies highlight the potential and ongoing exploration in using immersive environments for various aspects of the education process, however, these do not generally aim to compare their findings to more resource-intensive hands-on learning environments.

As this potential relates to this paper, while immersive technologies like virtual reality and augmented reality do not provide physical interaction like mock-up materials, they do afford simulating authentic activities in a realistic environment with significantly fewer resources due to the substitution of real materials with virtual objects. Especially for aspects of authentic learning that were not reported to require interaction with materials, such technologies would allow students to participate in an experience set in a realistic setting to simulate the authentic activity. Furthermore, due to the elimination of needing real materials and consequently the space required to accommodate an authentic activity, such simulations could also be integrated with classroom activities as opposed to authentic activities which are mostly available via extra-curricular events. While empirical evidence of learning outcomes through such simulations is needed, future researchers can include other characteristics identified in this paper in their virtual environments to test their efficacy in supporting the learning gains that were reported through authentic activities.

5.2. Limitations

Interview transcripts for both student and faculty were analyzed together as a single group in this study. However, there might be differences or new themes that might emerge specifically for each of these groups that were not discovered in this paper. Within the student groups, no distinction was made between graduate and undergraduate students to understand the effect of education level on the participant's experiences. While the results of this study extract from a comprehensive report from all participants, future researchers may add richness to these findings by identifying the differences between these groups to inform development and facilitation of cost-effective alternatives for authentic activities in the classroom.

6. Conclusion

This work presents the results of interviews with students and faculty who participated in authentic construction learning experiences. The findings are organized into characteristics that emerged as possible mechanisms behind the learning process. The interviewees did not directly suggest a relationship with the use of physical construction materials with most of the learning outcomes attributed to such activities. This is noteworthy because it is this characteristic of authentic activities that make them unique and expensive to conduct as compared to other modes of education. However, in some cases, the participants specifically highlighted the learning gains that were the result of interactions with real materials. These findings will help to inform how future research is conducted to strategically target similar types of learning with potentially fewer resources.

The contribution of this paper is in defining the specific characteristics of the authentic learning experience that participants reported to be valuable in the learning process and associated with specific learning outcomes. This understanding of the authentic learning experience and its beneficial characteristics will guide investment in learning activities and help target cost-effective alternatives to replicate similar learning outcomes. The potential for cost-effective pedagogical tools proposed in this article will also enable future researchers to empirically evaluate their efficacy for aspects of the learning process that did not immediately seem to require the use and interaction with authentic materials. The iterative nature of such exploratory analysis followed by confirmatory analysis by future research in this domain will allow educators to systematically design experiences that enable more students to participate in effective learning environments that prepare them with the skills necessary to succeed in their post-collegiate careers.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available since it is proprietary or confidential in nature and may only be provided with restrictions - Aggregated and anonymized interview responses.

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References

1. Figgess, G.W.; Vogt, R.G. Building Career-Ready Students through Multidisciplinary Project-Based Learning Opportunities-A Case Study. In Proceedings of the Proceedings of the 52nd {Annual} {Meeting} of the {ASEE} ({Volume} 1: {Long} {Papers}), 2017.
2. Khuzaimah, K.H.M.; Hassan, F. Uncovering Tacit Knowledge in Construction Industry: Communities of Practice Approach. *Procedia - Social and Behavioral Sciences* **2012**, *50*, 343–349. https://doi.org/10.1016/j.sbspro.2012.08.039.
3. Woo, J.H.; Clayton, M.J.; Johnson, R.E.; Flores, B.E.; Ellis, C. Dynamic Knowledge Map: reusing experts' tacit knowledge in the AEC industry. *Automation in Construction* **2004**, *13*, 203–207. https://doi.org/10.1016/j.autcon.2003.09.003.
4. Dewey, J. Experience and Education. new York: touchstone. *Original work published* **1938**, *1997*.
5. Kolb, D.A. Learning style inventory technical manual; McBer Boston, 1976.
6. Kolb, D.A. Experience as the source of learning and development. *Upper Sadle River: Prentice Hall* **1984**.
7. Piaget, J. The development of thought: Equilibration of cognitive structures. (Trans A. Rosin); Viking: Oxford, England, 1977.
8. E., B.L. Paradigm Shift in Construction Education is Vital for the Future of Our Profession. *Journal of Construction Engineering and Management* **2005**, *131*, 533–539. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:5(533).

9. Elrod, C.; Murray, S.; Flachsbart, B.; Burgher, K.; Foth, D. Utilizing Multimedia Case Studies to Teach the Professional Side of Project Management. Journal of STEM Education: Innovations and Research **2010**, pp. 7–17.
10. Hegazy, T.; Mostafa, K.; Esfahani, M.E. Hands-On Class Exercise for Efficient Planning and Execution of Modular Construction. *Journal of Civil Engineering Education* **2020**, *146*, 05020002. https://doi.org/10.1061/(ASCE)EI.2643-9115.0000012.
11. Pathirage, C.; Amaratunga, D.; Haigh, R. The role of tacit knowledge in the construction industry: towards a definition. *CIB W89 International Conference on Building Education and research* **2008**.
12. Barnes, H. Impact Evaluation of the U.S. Department of Energy's Solar Decathlon Program. https://doi.org/10.2172/1219938.
13. Klahr, D.; Triona, L.M.; Williams, C. Hands on what? The relative effectiveness of physical versus virtual materials in an engineering design project by middle school children. *Journal of Research in Science teaching* **2007**, *44*, 183–203.
14. Park, C.S.; Le, Q.T.; Pedro, A.; Lim, C.R. Interactive Building Anatomy Modeling for Experiential Building Construction Education. *Journal of Professional Issues in Engineering Education and Practice* **2016**, *142*, 04015019. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000268.
15. Radu, I. Augmented reality in education: A meta-review and cross-media analysis. *Personal and Ubiquitous Computing* **2014**, *18*, 1533–1543. https://doi.org/10.1007/s00779-013-0747-y.
16. Bonwell, C.C.; Eison, J.A. *Active Learning: Creating Excitement in the Classroom. 1991 ASHE-ERIC Higher Education Reports*; ERIC Clearinghouse on Higher Education, The George Washington University, One Dupont Circle, Suite 630, Washington, DC 20036-1183 ($17, 1991.
17. Gosen, J.; Washbush, J. A Review of Scholarship on Assessing Experiential Learning Effectiveness. *Simulation & Gaming* **2004**, *35*, 270–293. https://doi.org/10.1177/1046878104263544.
18. Johnson, D.W.; Johnson, R.T.; Stanne, M.B. Cooperative learning methods: A meta-analysis **2000**.
19. Michael, J. Where's the evidence that active learning works? *Advances in Physiology Education* **2006**, *30*, 159–167. https://doi.org/10.1152/advan.00053.2006.
20. Prince, M. Does Active Learning Work? A Review of the Research. *Journal of Engineering Education* **2004**, *93*, 223–231. https://doi.org/10.1002/j.2168-9830.2004.tb00809.x.
21. Liegel, K.M. Project-Based Learning and Future Project Management. 2004.
22. Marshall, P.P.; Click, D.; Craft, S. The Solar Decathlon And Abet Ec 2000. In Proceedings of the ASEE Anual Conference 2004, June 2004.
23. Choe, N.H.; Martins, L.L.; Borrego, M.; Kendall, M.R. Professional Aspects of Engineering: Improving Prediction of Undergraduates' Engineering Identity. *Journal of Professional Issues in Engineering Education and Practice* **2019**, *145*, 04019006. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000413.
24. Hegazy, T.; Abdel-Monem, M.; Saad., D.A.; Rashedi, R. Hands-On Exercise for Enhancing Students' Construction Management Skills. *Journal of Construction Engineering and Management* **2013**, *139*, 1135–1143. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000705.
25. Kuennen, S.T.; Pocock, J.B. Bringing Construction Experience into the Classroom. In Proceedings of the Construction {Research} {Congress}, Honolulu, Hawaii, United States, March 2003; pp. 1–8. https://doi.org/10.1061/40671(2003)56.
26. Sirianni, V.L.; Lee, K.L.; LeFevre, M.D.; Lindholm, J.W. Assessing the Impact of the Concrete Canoe and Steel Bridge Competitions on Civil Engineering Technology Students. In Proceedings of the 2003 Annual Conference, 2003, p. 15.
27. Martín-Gutiérrez, J.; Mora, C.E.; Añorbe-Díaz, B.; González-Marrero, A. Virtual Technologies Trends in Education. *Eurasia Journal of Mathematics, Science and Technology Education* **2017**, *13*, 469–486. https://doi.org/10.12973/eurasia.2017.00626a.
28. Yannier, N.; Hudson, S.E.; Wiese, E.S.; Koedinger, K.R. Adding physical objects to an interactive game improves learning and enjoyment: Evidence from EarthShake. ACM Transactions on Computer-Human Interaction (TOCHI) **2016**, 23, 1–31.
29. Gall, M.D.; Gall, J.P.; Borg, W.R. *Educational research: an introduction*, 7th ed.. ed.; Allyn and Bacon: Boston, 2003.
30. Creswell, J.W.; Poth, C.N. Qualitative inquiry and research design: Choosing among five approaches; Sage publications, 2016.

31. Maxwell, J.A. Expanding the history and range of mixed methods research. *Journal of mixed methods research* **2016**, *10*, 12–27.
32. Boyatzis, R.E. Transforming qualitative information: thematic analysis and code development; Sage Publications: Thousand Oaks, CA, 1998.
33. Bjorklund, S.A.; Colbeck, C.L. The view from the top: Leaders' perspectives on a decade of change in engineering education. Journal of Engineering Education **2001**, 90, 13–19.
34. Marshall, C.; Rossman, G.B. *Designing qualitative research*; Sage publications, 2014.
35. Chandrasekaran, S.; Stojcevski, A.; Littlefair, G.; Joordens, M. Learning through Projects in Engineering Education. *SEFI Annual Conference* **2012**, p. 9.
36. Holt, E.A. Students Involvement in the Solar Decathlon Competition: Giving Context to the Classroom Experience. In Proceedings of the {ASC Annual International Conference Proceesings} {Evolving} {Construction}: {Towards} a technological revolution, 2012, p. 7.
37. Kaufmann, H.; Dünser, A. Summary of usability evaluations of an educational augmented reality application. In Proceedings of the International conference on virtual reality. Springer, 2007, pp. 660–669.
38. Morrison, A.; Oulasvirta, A.; Peltonen, P.; Lemmela, S.; Jacucci, G.; Reitmayr, G.; Näsänen, J.; Juustila, A. Like bees around the hive: a comparative study of a mobile augmented reality map. In Proceedings of the Proceedings of the SIGCHI conference on human factors in computing systems, 2009, pp. 1889–1898.
39. Freitas, R.; Campos, P. SMART: a System of augmented reality for teaching 2nd grade students. *People and Computers XXII Culture,* Creativity, Interaction **2008**, pp. 27–30.
40. Grantcharov, T.P.; Kristiansen, V.B.; Bendix, J.; Bardram, L.; Rosenberg, J.; Funch-Jensen, P. Randomized clinical trial of virtual reality simulation for laparoscopic skills training. *The British Journal of Surgery* **2004**, *91*, 146–150. https://doi.org/10.1002/bjs.4407.
41. Seymour, N.E.; Gallagher, A.G.; Roman, S.A.; O'Brien, M.K.; Bansal, V.K.; Andersen, D.K.; Satava, R.M. Virtual reality training improves operating room performance: results of a randomized, double-blinded study. *Annals of Surgery* **2002**, *236*. https://doi.org/10.1097/00000658-200210000-00008.
42. Washburn, D.A.; Jones, L.M.; Satya, R.V.; Clint, D. Olfactory use in virtual environment training. *Modeling and simulation.* **2003**, *2*, 19.
43. Patil, K.R.; Ayer, S.K.; Wu, W.; London, J. Mixed Reality Multimedia Learning To Facilitate Learning Outcomes From Project Based Learning, Phoenix, Arizona, 2020.
44. Chalhoub, J.; Ayer, S.K. Using Mixed Reality for electrical construction design communication. *Automation in Construction* **2018**, *86*, 1–10. https://doi.org/10.1016/j.autcon.2017.10.028.
45. Khalek, I.A.; Chalhoub, J.M.; Ayer, S.K. Augmented Reality for Identifying Maintainability Concerns during Design, 2019.
46. Wu, W.; Hartless, J.; Tesei, A.; Gunji, V.; Ayer, S.; London, J. Design Assessment in Virtual and Mixed Reality Environments: Comparison of Novices and Experts. *Journal of Construction Engineering and Management* **2019**, *145*, 04019049. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001683.
47. Albert, A.; Hallowell, M.R.; Kleiner, B.; Chen, A.; Golparvar-Fard, M. Enhancing Construction Hazard Recognition with High-Fidelity Augmented Virtuality. *Journal of Construction Engineering and Management* **2014**, *140*, 04014024. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000860.
48. Bhandari, S.; Molenaar, K.R. Using Debiasing Strategies to Manage Cognitive Biases in Construction Risk Management: Recommendations for Practice and Future Research. *Practice Periodical on Structural Design and Construction* **2020**, *25*, 04020033. https://doi.org/10.1061/(ASCE)SC.1943-5576.0000521.
49. Mani, G.F.; Silvio, S.; Peña-Mora Feniosky. Interactive Visual Construction Progress Monitoring with D4 AR ? 4D Augmented Reality ? Models. *Building a Sustainable Future* **2012**, pp. 41–50. https://doi.org/10.1061/41020(339)5.