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Multidisciplinary Authoring – A Critical Foundation for Augmented Reality Systems in Training and Education

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At Bell Laboratories Dr. Thompson created with the Vice President of Research and Nobel laureate, Arno Penizas, the W. Lincoln Hawkins Mentoring Excellence Award (1994). This award is given to a member of the research staff for fostering the career growth of Bell Labs students and associates. This award is ResearchÄôs highest honor for mentoring contributions. In 1998, AT&T Labs instituted a similar award named for Dr. Thompson.

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His awards include the US Presidential Award for Excellence in Mentoring; Tau Beta Pi Eminent Engineer; James E. Blackwell Scholar; AT&T Bell Laboratories Cooperative Research Fellowship. He is cited in WhoÄôs Who among African Americans, Education, and Technology Today; American Men and Women of Science, West Babylon Alumni Hall of Fame; He is a Fellow of the Acoustical Society of America and cited for his fundamental contributions to theoretical and computational acoustics. He is senior member of IEEE, and a member of the American Physical Society and Sigma Xi. He has published reesearch in acoustics, control theory, fluid mechanics, heat transfer, linear and nonlinear systems, and telecommunications.

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Multi-Disciplinary Authoring – A critical foundation for Augmented Reality Systems in Training and Education

Abstract

Recent advances in Augmented Reality (AR) devices and their maturity as a technology offers new modalities for interaction between learners and their learning environments. Such capabilities are particularly important for learning that involves hands-on activities where there is a compelling need to: (a) make connections between knowledge-elements that have been taught at different times, (b) apply principles and theoretical knowledge in a concrete experimental setting, (c) understand the limitations of what can be studied via models and via experiments, (d) cope with increasing shortages in teaching-support staff and instructional material at the intersection of disciplines, and (e) improve student engagement in their learning.

AR devices that are integrated into training and education systems can be effectively used to deliver just-in-time informatics to augment physical workspaces and learning environments with virtual artifacts. We present a system that demonstrates a solution to a critical registration problem and enables a multi-disciplinary team to develop the pedagogical content without the need for extensive coding. The most popular approach for developing AR applications is to develop a game using a standard game engine such as UNITY or UNREAL. These engines offer a powerful environment for developing a large variety of games and an exhaustive library of digital assets. In contrast, the framework we offer supports a limited range of human-environment interactions that are suitable and effective for training and education. Our system offers four important capabilities – annotation, navigation, guidance, and operator safety. These capabilities are presented and described in detail.

The above framework motivates a change of focus – from game development to AR content development. While game development is an intensive activity that involves extensive programming, AR content development is a multi-disciplinary activity that requires contributions from a large team of graphics designers, content creators, domain experts, pedagogy experts, and learning evaluators. We have demonstrated that such a multi-disciplinary team of experts working with our framework can use popular content creation tools to design and develop the virtual artifacts required for the AR system. These artifacts can be archived in a standard relational database and hosted on robust cloud-based backend systems for scale up. The AR content creators can own their content and Non-fungible Tokens to sequence the presentations either to improve pedagogical novelty or to personalize the learning.

I. Introduction

Augmented Reality (AR) devices that offer immersive experiences for users have matured significantly in recent years [1]. When incorporated effectively into systems, such devices can now help to address many of the challenges brought about by the digital transformation initiatives in manufacturing, health, and education [2]-[10]. AR devices can super-impose virtual informatics on objects and spaces in the physical environment of the user. The term informatics, in general, refers to the science of collecting, organizing, and disseminating information to people using computers [11]. In the context of our AR system discussed in this work, actionable information is shared with the people wearing the AR device. This information can be a simple label, a detailed simulation report, an audio or video file, a CAD model, or an animation. The main objective is to empower the user to perform the action correctly and educate them with contextual information. This ability to offer just-in-time informatics in the physical workspace of a potential user creates new opportunities for workforce training, that include transfer of knowledge from experts to trainees, rapid acquisition of new skills, and the safe execution of acquired skills. For students and educators, such systems offer a personalized learning portal, enabling new models of pedagogy in STEM education that emphasizes engagement of students across traditional disciplinary boundaries [10]. Thus, there is considerable interest to better understand the extent to which such technologies can support future workers, students, and educators to become more efficient in embracing digital transformation, and to play a role in improving its use [12].

There are several challenges one must confront to design and deploy effective AR systems. First, most AR systems are structured around a game engine, a software framework designed to create interactive media and engaging personalized experiences through a complex sequence of interactions [13]. Mastering the software pipeline associated with a game engine is often a serious technological barrier that may prove challenging for one without a breadth of experience in the field to overcome. Education and training systems do not require complex game plays, interaction modalities, or challenges, even when the AR content must be delivered in an immersive and personalized manner. Second, most of the effort involves the identification, design, and delivery of effective AR content, which is, perforce, a multidisciplinary endeavor. However, this requires a reduction in these technological barriers so that such teams can collaborate effectively during the content creation process. Third, the delivery of AR informatics must be designed to cope with a variety of situations that can occur either because of a user's background or due to uncertainties encountered in the physical layout of said user's workspace. Fourth, the *requirements —> design —> implementation —> operation* continuum in many complex environments is necessarily an iterative process. Effective modeling tools and approaches can mitigate the risk of inconsistencies across this continuum. Finally, the future behaviors of users are likely to be tightly intertwined with future technology advances, and, hence, effective AR systems must integrate the best practices for engaging users in the research and design of the system. Participatory action research (PAR), for example, prioritizes the active participation of all stakeholders to create an inclusive action process for problem-solving and constructive change management. AR systems in the future can better address these challenges if the content creation process is accessible to a broad spectrum of domain experts.

The no-code AR Systems Framework (NCARS) [14]-[16] that we describe in this paper addresses the above challenges by disentangling the AR content from the underlying game engine as described in more detail in Section III. This separation enables designers of AR systems to focus on the creation of effective AR content by working around the technology barriers imposed by game engines, AR device limitations, and the ever-increasing plethora of software tools.

For content to be effective, it should be created by multi-disciplinary teams of domain experts, reflecting best practices in pedagogy, knowledge domains, student engagement, and learning evaluation. For example, graphics designers, animators, and digital artists can create content that is contextually relevant and aesthetically inviting to users with well-chosen visual and audio effects. Domain experts must identify the content that appropriately targets the users at their level of readiness and learning objectives. Pedagogy experts can co-create with the domain experts and digital artists to package content in a way that improves learning. CAD modelers can create effective representations of the physical environment and the artifacts of interest. Photographers can create supplemental images and videos to support the pedagogy. The contributions of such a diverse team must come together in a cohesive manner where the value of the whole is greater than the sum of the parts.

The next section describes the current state of practice in AR systems design and identifies some of the technology barriers that impede a multi-disciplinary team from collaborative authoring as highlighted above.

II. Current state of AR systems design and development

The existing methods for Augmented Reality (AR) application development are challenging, especially in multi-disciplinary team settings. Typically, the development of AR applications for AR devices, such as the Microsoft HoloLens, requires a game engine. For HoloLens, there are two main supported engines to choose from: Unity and Unreal Engine 4. These game engines must be configured for developing applications using the Mixed Reality Toolkit (MRTK), which is an open-source resource that allows the game engine to interact with and build HoloLens applications. These applications are designed using interactive environments, called scenes, in Unity. These scenes contain "Objects" that can take many forms, including but not limited to 3D Models, audio files, images, and video. The properties and interactions between these objects are manipulated with the use of C# scripts. After a project is built in the game engine, it must be either deployed directly to HoloLens or transferred to an application package for later installation using Visual Studio and the Microsoft Device Portal. If a member of a multi-disciplinary team with varying coding backgrounds needs to make any changes to the application, such as adding a new scene or 3D model, they must be well-versed in the intricacies of the game engines [17] and have considerable experience in a software pipeline that includes all of the tools for rendering, modeling, animation, programming in a language such as C#, debugging scripts, configuring libraries and devices in a consistent manner, and have familiarity with device tethering and network connectivity, and configuration. Game designers are also usually aware of collections of 3D models that are available to make their work more efficient.

The AR application development process is often focused on a particular AR device. The approach typically involves using a game engine to create an immersive person-centered experience [18]. Game engines such as Unity3D support the developers to render 2D or 3D graphics, to detect collisions and respond, to present sound, scripts and animations, to network with other compute and storage devices, to stream data, and to track the position of the users in the environment. Software tools also help developers to create and test the AR content before deploying to the AR device as illustrated in Figure 1. For example, a CAD model of the physical system is often used to capture its structure and important features that the user may interact with. It is important to note that the content creators must first create the digital content and pass it off to the AR system designer to package and deliver the content.

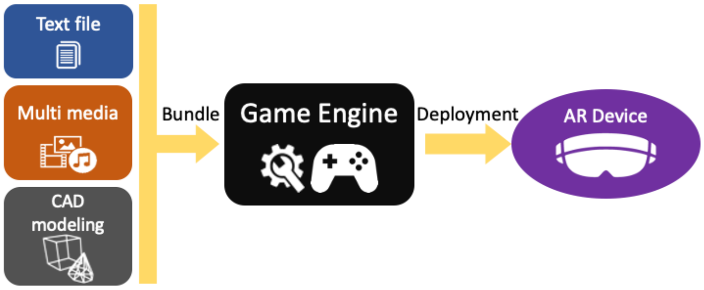


Figure 1: A Game Engine is used to integrate AR Content into one application that is deployed on a particular AR Device. The user must wear this device to use the AR Application.

An AR application that is developed using this approach often serves a single-purpose, and its AR contents cannot be changed easily after deployment. The pre-populated content is often based on the experience of a few trained professionals, who may have had prior experience with similar content. These systems are difficult to personalize to the needs and preferences of the individual users.

The content is presented to the users when a set of defined event triggers are recognized. If the AR content relies on information in an underlying CAD model, which was created when the physical environment was designed, such an approach is not likely to be useful especially when components and subsystems may change. When changes such as a revision to the 3D models are necessary, the developer must re-work the entire development process and re-deploy the application. This approach is tedious and requires considerable programming maturity before the designers can be effective. Moreover, the designers may not have the domain knowledge that could be helpful in the process redesign.

III. No-Code AR Systems Framework

The no-code AR Systems Framework (NCARS) that is described in this paper is an approach to AR systems development that disentangles the AR content from the underlying game engine. The NCARS enables a multi-disciplinary team of content creators to use software tools that they are already familiar with to create AR content. The NCARS integrates this content and creates an AR application that is useful in a variety of training and education contexts.

The central idea in the NCARS is that of an Immersive Action Unit (IAU). An IAU is the AR content presented to the user via the AR device at a given point in time. An IAU may include text, image, video, audio, graphics, animation, CAD model, or any digital artifact. Instead of hardcoding these digital artifacts into the AR Application, these artifacts are treated as data and retrieved from a database as needed. The purpose of presenting an IAU to a user is to elicit or guide some specific action in the physical environment. When the user action is completed, the system presents the next IAU. In the NCARS, an AR Application is a sequence of IAUs. Content creators develop both the content and the sequence or dependencies that constrain their presentation to the user. Thus, the NCARS abstracts away many details of the underlying game engine and instead of complex game plays with rich interaction experience, the framework presents a simple user-system interaction model that is contextualized by the IAUs. Such a model adequately covers the needs in several training and education contexts. It includes the following four key activities:

1. **Annotation**: present just-in-time informatics about objects of interest to the user,
2. **Navigation**: present navigational signs to help the user identify objects of interest or physically navigate complex work environments,
3. **Guidance**: present the user a sequence of IAUs to guide the completion of a task sequence, and
4. **Safety**: present the status of safety parameters and alarms, as configured by the user.

The NCARS achieves its objectives by relying on the system architecture that is illustrated in Figure 2. From the perspective of the NCARS, an AR device is a sophisticated display device. It is sophisticated because it has a field of view that offers the user an immersive experience, it can project holograms within the field of view, it supports spatial sound, and allows the user to interact with and experience a physical environment. The AR device can recognize a collection of gestures and supports voice-based interactions with the users. The IAU server is a repository of all IAUs that are stored in a standard relational database with an SQL front-end. The AR device interacts with the IAU Server using a request-response model. Typically, upon completing the action step associated with an IAU, the user should request the next IAU. The Operator and System Safety subsystem collects data from the physical environment and the operator safety equipment. All of this data is pushed to the AR device by the IAU server. The

AR device can also initiate requests for annotations and navigation via the CAD server, again using a request-response model. Responses for valid requests are sent back to the AR device. A live stream from the AR device can be viewed by other staff or trainees at a monitoring station. The monitoring station can also be used to monitor progress of a maintenance mission by replaying the historical status captured in the IAU server.

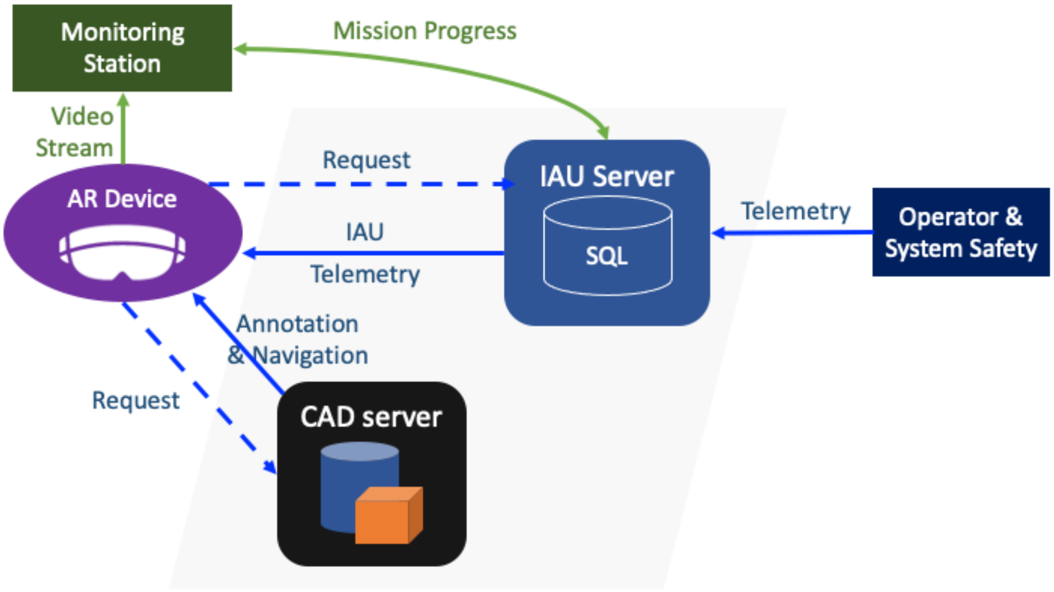


Figure 2: The underlying system architecture of the AR Systems Framework includes multiple servers. This architecture enables AR content to be disentangled from the software that presents the content to users.

AR system designers who use the NCARS can now focus on creating the AR content and designing the flow, or sequences, in which these content items can be presented to users as IAUs. This fundamental change in the work pattern is illustrated in Figure 3 and offers several advantages over the approach in Figure 1. Notably, the content-centric approach of the framework serves as a conduit between content creators and content consumers, via the AR devices without entangling these contents with the underlying game engine.

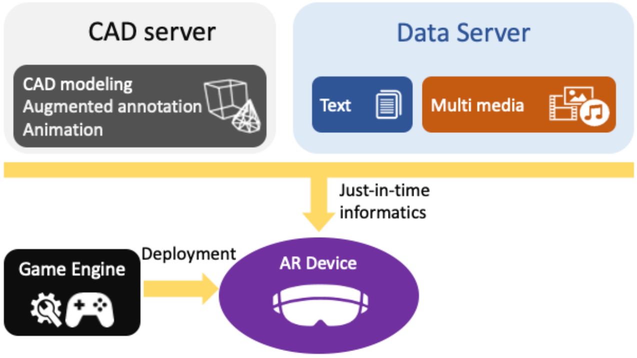


Figure 3: The system architecture fundamentally changes the role of the game engine. The software developed using the game engine retrieves the contents from the servers before presenting to users.

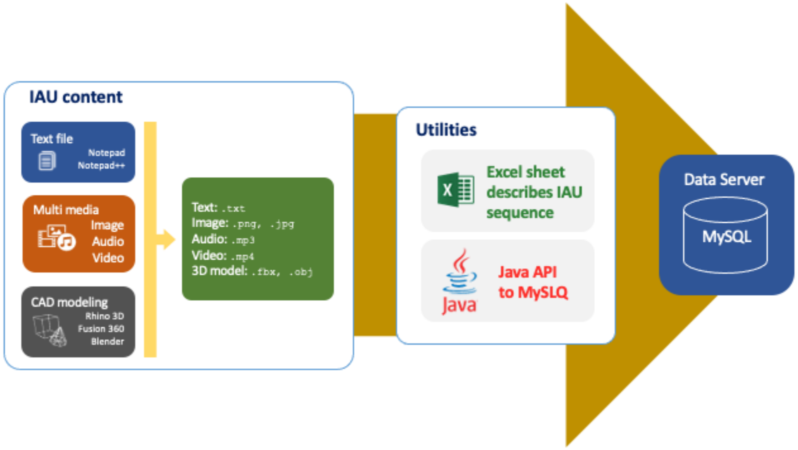


Figure 4: AR Content creators can use familiar software and productivity tools to create the virtual artifacts. These virtual artifacts must be assembled into IAUs and uploaded to the IAU Server. In this manner, the no-code AR framework enables content creators

It is important to note that the four key activities of the NCARS, i.e., annotation, navigation, guidance, and safety relies on the full power of the underlying game engine. However, AR content creators and AR system designers who use the NCARS do not need to manipulate or modify this software. Instead, AR content designers can use software applications they are familiar with, such as the ones illustrated in Figure 4, to create content that is appropriate to their expertise. This content must be assembled into IAUs and loaded into the IAU server that is shown in Figure 2. These tools can be readily utilized in education and training or participatory action research settings, to create, update, and deploy AR systems without the need to develop extensive code. This process of content creation by a multi-disciplinary team will be explained in the context of a specific example in Section IV of this paper.

IV. AR-content example for tabletop conveyor system

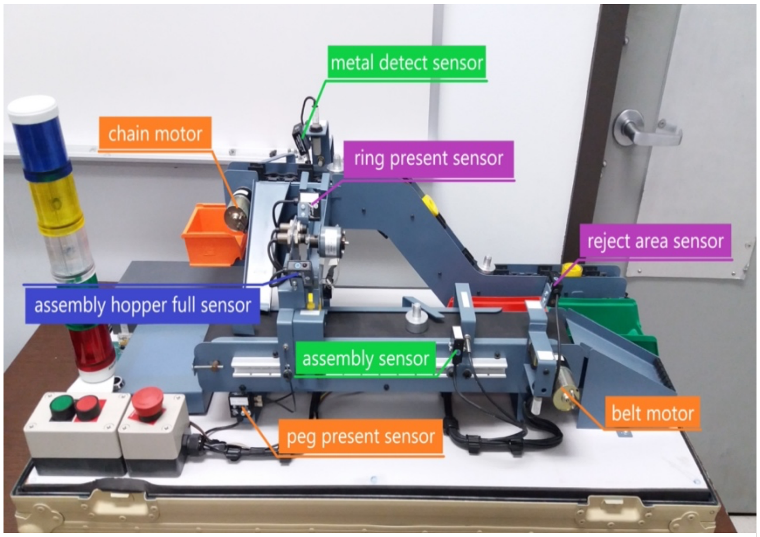
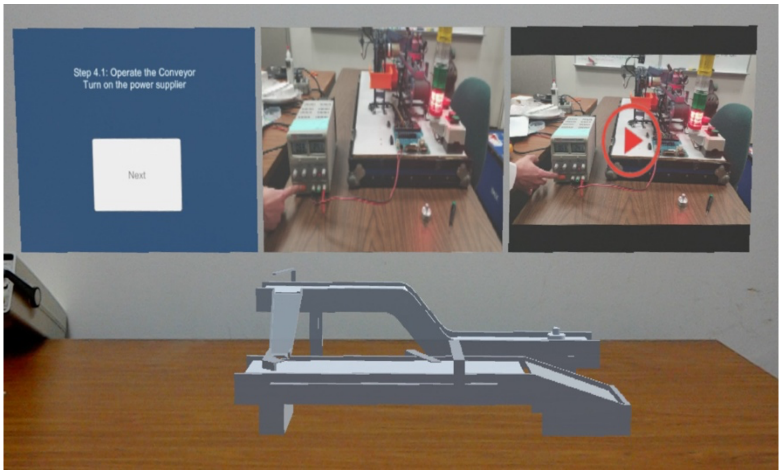


Figure 5: The Tabletop Conveyor System is a real physical system and the colored labels are all virtual artifacts that can only be seen when the user is wearing an AR device

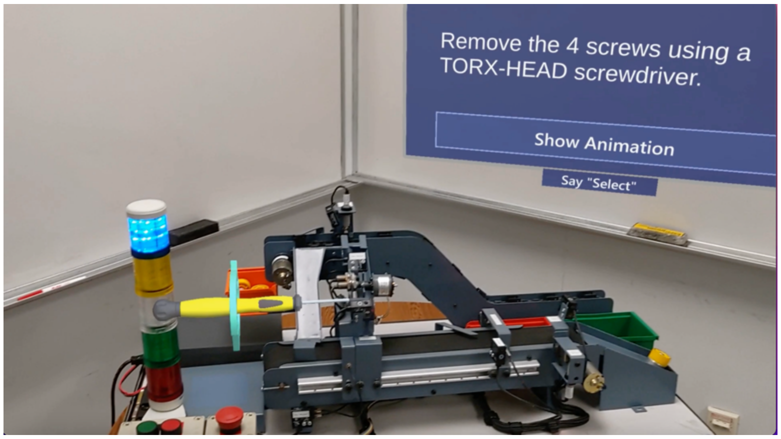
Consider the tabletop conveyor system shown in Figure 5. A user who is wearing an immersive AR device can see and interact with the physical system to place parts in position or press the buttons to start and stop the conveyor demonstration. In addition, the user's field of view in the AR device can be augmented with a variety of virtual artifacts. In Figure 5, the colored labels are all virtual artifacts that have been created using Microsoft PowerPoint. These labels are stored as digital artifacts in the IAU database shown in Figure 3. When the AR application for this conveyor is launched, the software of the no-code AR framework guides the users to complete a calibration procedure. A pair of transformation matrices are obtained upon completion of this calibration step as described in [16]. The no-code framework utilizes these transformations to precisely place the digital artifacts in the user's field of view to create the illusion of labels that are shown in Figure 5.

To guide the users in completing a sequence of tasks, we need several IAUs. Figure 6 shows a representative IAU. In clockwise direction starting at the top left, there is a textbox. The content of this textbox, i.e., the text is stored as a string in the IAU database. In the top middle of the figure, there is an image. This picture was taken using a smartphone camera. The size of and resolution of the picture was adjusted to be compatible with the size constraints imposed by the network link between the AR device and the IAU server and the responsiveness required by the users. The top right part of Figure 6 is a video clip that was also captured using a smartphone. The duration, location, orientation, lighting, and relevance of this clip are choices that the multi-disciplinary authoring team must make. Once recorded, the video clip is treated as a labeled digital artifact that is stored in the IAU and retrieved when needed for presentation in the user's field of view. Finally, the bottom center of the figure shows a CAD model for the conveyor system that emphasizes the belts that carry the parts. This CAD model was created using Rhino, a 3D modeling software [19] and incorporated as a digital artifact in the IAU database.



Step 4.1: Operate the Conveyor
Turn on the power supplier

Figure 6: A representative IAU for the Tabletop Conveyor System that is shown in Figure 5. This IAU was created using off-the-shelf tools shown in Figure 4.



Remove the 4 screws using a TORX-HEAD screwdriver.

Figure 7: A simpler IAU that has a textbox and an animation of a virtual screwdriver.

IAUs can be complex as illustrated in Figure 6 or simple as shown in Figure 7. In this IAU there is a textbox and animation of a virtual screwdriver that was created using Blender [20]. The animation is stored as a digital artifact in the IAU database that is retrieved and presented by the no-code framework as needed.

The last example of an IAU for the conveyor system is shown in Figure 8. In this IAU there are object identifier labels that were discussed before. In addition, there is a structured textbox that is populated with content that is specific to the object of interest. In this example, the object of interest is the motor that drives one of the belts of the conveyor system. The details pertaining to this motor are its part number, the last date of maintenance, and its recent performance. This example highlights that the IAUs are in fact very general and versatile and can include any digital artifact that can either be created either by using an off-the-shelf tool such as the ones shown in Figure 4, or by programmatically synthesizing the content dynamically. The no-code framework does not restrict content designers and supports both approaches.

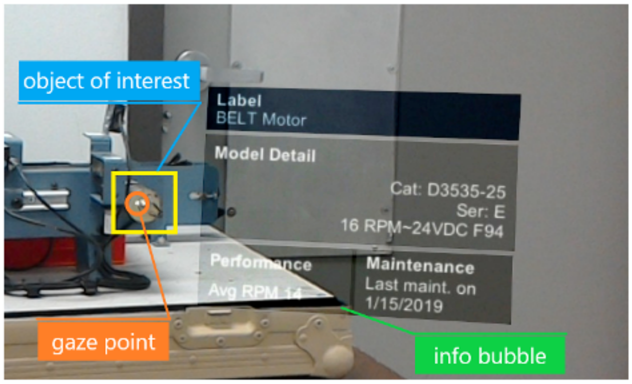


Figure 8: IAU showing details of a motor and labels.

In addition to designing IAUs, AR content creators must specify a flow-table that is also stored on the IAU database [16]. This table specifies the sequences in which IAUs must be presented to the user for completing a specific guided task. Thus, each guidance activity is associated with a unique flow-table; this table and the associated IAUs is the content associated with each “Guidance” task of the system. The Annotation feature is simpler because there is no flow-table and only individual IAUs are used. The Navigation feature only presents directional signs instead of the IAUs and the orientations of these signs are computed dynamically with support from the CAD server [16].

As highlighted in this detailed example, the IAUs are the only pedagogical or training interface for the users of the AR system. The AR system for training and education that is created using the no-code systems framework is a sequence of IAUs. Thus, these IAUs must be created with care guided by considerations from multiple disciplines. For example, designing IAUs may involve the input from:

- a domain expert for relevance,
- a graphic designer for creating digital artifacts and with appropriate orientation and lighting,
- a pedagogy expert for the sequence of operations and duration,
- a psychology expert for issues related to attention and focus,

- an expert camera person to create a professional images and videos,
- a sociologist to account for access, diversity, and inclusivity issues,
- a learning evaluator to assess effectiveness,
- an engineer to create CAD models, and
- business process owners to integrate the training into larger processes.

Clearly, such a diverse team of experts cannot be hosted by every organization and without such a team it is unlikely that effective AR content can be created. In the current state-of-the-practice, game designers integrate many of these considerations by interacting with teams of experts in the model illustrated in Figure 1. This approach is limiting, and domain experts do not retain ownership of their content. In contrast, the approach supported using the no-code framework (Figure 3 and Figure 4) enables content creators to design and deploy effective content unencumbered by the technology barriers imposed by the game engines and their idioms. The domain experts can evolve the content to address needs of different learning audiences and monetize their intellectual property in the digital economy through NFTs.

This research also investigated the benefits of engaging users as potential content creators through participatory action research (PAR); this engagement helps to build the collaborative community needed for fully utilizing the no-code framework described above. Utilizing the AR application for the conveyor belt physical system, a group of eight participants with varied domain expertise were recruited. The expertise included: (i) an undergraduate engineering laboratory instructor with systems knowledge; (ii) a laboratory technician; (iii) two professional student advisors familiar with the issues that students' face in their freshman and sophomore year lab experience; (iv) an administrative assistant in the college of engineering; (v) two engineering students (one in the junior year of mechanical engineering with limited industry experience and another in the engineering technology degree program with significant experience in industry working in a torpedo manufacturing plan; and finally (vi) a nursing Ph.D. student who has used Virtual Reality (VR) to demonstrate nursing interventions and is also an information educator for AI.

The objective of engaging these participants was to determine their opinions on the application of this technology and in particular consider these data in the context of their own background and experience in their individual work contexts.

V. Participatory action research for engaging content creators

Participatory action research (PAR) is a research framework that prioritizes the experiences and concerns of the people directly impacted by the project and involves them in identifying and implementing constructive changes. To initiate this process, we designed and conducted two focus groups that were facilitated by a member of the research team. All eight participants attended the first focus group, and seven participants attended the second focus group. The graphic in Figure 9 highlights the first stage of PAR that was implemented in this research. PAR is typically iterative in addressing the issues that participants identify and the action items that they may take on to address these issues, which are then further evaluated to determine if improvements are in place.

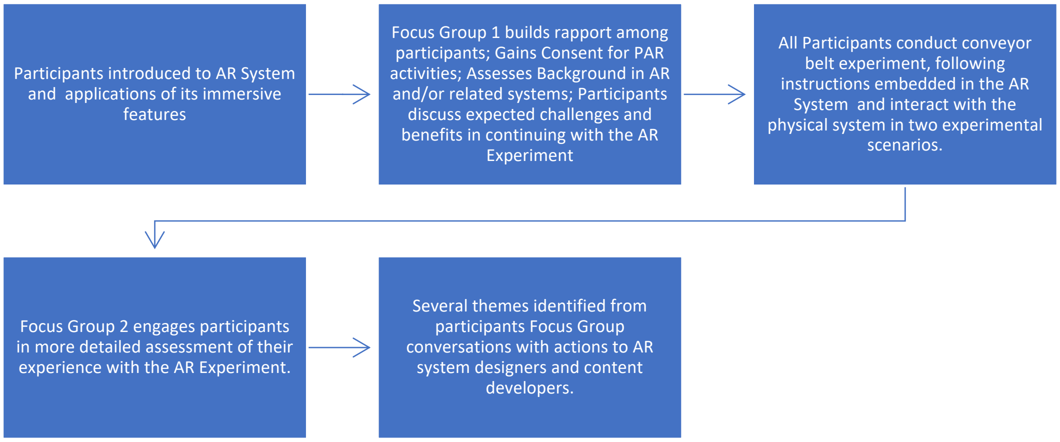


Figure 9: Sequence of PAR activities.

Figure 10: AR experiments for inter-generational participants.

The first focus group was conducted in person immediately after the participants' first introduction to the AR system to be used for the experiment. After the consent process was completed, participants were asked to explain their own prior experience using AR or VR devices and with working in manufacturing or doing assembly line tasks. These questions were necessary to understand how the background experiences of the participants may affect their reactions to the AR-assisted tasks in this project. After this, they were asked to reflect on their expectations for the experiment, including both expected benefits and challenges, and to consider any safety concerns. To ensure that all voices were heard, participants first wrote down their comments on sticky notes and then posted them on the board. In the discussion, all comments were reviewed and considered.

Focus group 1 outcomes:

Prior Experience: Of the eight participants, none of them had prior experience using an AR device. Six mentioned they had prior experience using a VR device, including three who had used an Oculus system. The remaining two participants had no experience with VR devices. Only one participant mentioned he had prior experience working in manufacturing.

Figure 11 captures some of the challenges and benefits that were identified from the first focus group.

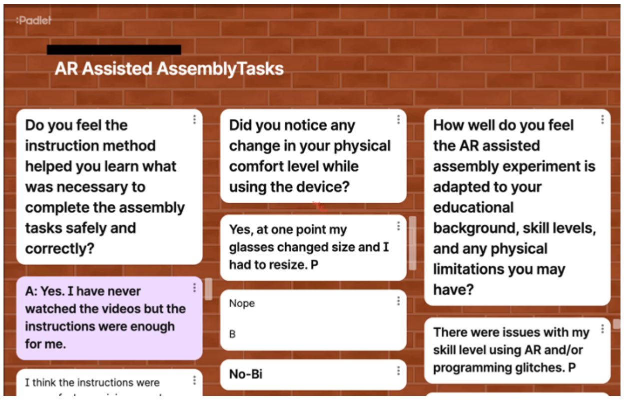
Expected Cognitive Challenges	Expected Physical Challenges	Expected Benefits
•Learning something new •Keeping up with the pace •Lack of experience •Maintaining attention •Understanding the terms or instructions	•Not having enough space •Discomfort due to wearing glasses •Motion sickness •Not being at the correct depth to register AR output •Not having time to participate	•Learning something new •Improving the future of AR •Participating in the progression of AR in manufacturing •Gaining experience with AR •Having a better focus group experience

Figure 11: Outcomes from first focus group on expected challenges and benefits.

Safety/Comfort Concerns: Participants provided very useful feedback based on their initial introduction to using the AR device. With regard to safety, they mentioned concerns with the physical set-up such as a cable on the floor and being located near a doorway. As for comfort, several people mentioned issues with adjusting the visor; they felt it would be better to adjust this first, to avoid blurriness or discomfort. Another person mentioned issues with a cord that was behind her arm, and someone else thought the set-up may need to be adjusted depending on whether people would be sitting or standing, to allow easy viewing of the instructions.

Focus group 2 outcomes:

The second focus group was conducted after participants had completed the AR assisted assembly tasks. This meeting was scheduled on Zoom due to conflicting work schedules. We used Mentimeter and Padlet, applications that allow participants to post their thougts and experiences directly using virtual “sticky notes” and word clouds [21], [22].



[redacted]

AR Assisted AssemblyTasks

Do you feel the instruction method helped you learn what was necessary to complete the assembly tasks safely and correctly?

A: Yes. I have never watched the videos but the instructions were enough for me.

I think the instructions were

Did you notice any change in your physical comfort level while using the device?

Yes, at one point my glasses changed size and I had to resize. P

Nope

B

No-Bi

How well do you feel the AR assisted assembly experiment is adapted to your educational background, skill levels, and any physical limitations you may have?

There were issues with my skill level using AR and/or programming glitches. P

Figure 12: Virtual interaction in PAR focus group with Padlet application.

Prompt 1: “In one word, how would you describe your experiences in this project with AR-assisted assembly tasks?”

The participants were divided between four who mentioned positive words (i.e., "great, good, fantastic, simple, easy”) three with more negative ones (i.e., confusing, convoluted, tricky), and one who said “simple,” but then explained further that if he could add a second word, he would say “confusing” as well. This participant, who had no prior experience with AR-assisted devices, explained that he felt completing the tasks did not take long and was simple, but there were times when he wasn’t understanding the instructions, or the instructions could have been clearer.

Prompt 2: “Do you feel the instruction method helped you learn what was necessary to complete the AR-assisted assembly tasks safely and correctly?”

Two participants, both of whom had considerable prior experience with VR devices, felt the instructions were clear—one emphasized the assistance of the videos, whereas the other stated they did not watch the videos, but the “instructions were enough for me.” The remaining five participants had more mixed responses, ranging from characterizing the instructions as “the bare minimum” to emphasizing that they used mainly “trial and error” to complete the tasks. One participant further clarified: “I needed a lot more guidance and time to process the multiple steps when following the directions.”

Prompt 3: “Do you see changes needed in comfort while using the device?”

Four participants did not experience significant discomfort, whereas one participant mentioned possible neck problems with repeated use and another had to resize due to their glasses affecting the size.

Prompt 4: “*How well was this experiment adapted to your educational background, skill levels, and any physical limitations you may have?”*

Comments ranged from “I had no physical limitations and I think the program did a good job explaining the mechanics of the process for a beginner” to several others who felt the instructions and comfort level needed more attention. In the words of one participant, "General understanding and comfortability using the technology could be improved as I’ve had no experience using AR previously. This is an entire new world for me, so clear instructions and an opportunity for trial and error or information videos would be beneficial.”

Prompt 5: “Specific suggestions for improvements?”

Responses included: “Allow folks to go back at all stages in case of error,” “more details on what the expectations for which step are,” “more practice before the experiment, “longer tasks/more time using the technology . . . [to] increase the feedback I could offer,” “a larger (but not large) focus group,” “make the equipment wireless,” and “maybe a more elaborate assembly process that would be less predictable so I can see how well I could rely on the program.”

Prompt 6: “Would you consider using the AR system with appropriate applications developed to assist in your own work or professional development?

Three participants responded “definitely,” with the participant who had used VR in nursing education mentioning that the AR system was “so much easier than VR technology” and that “if the learning objectives are compatible with AR technology, I would use it in my simulation sessions.” Only one participant responded “N/A,” explaining that the AR system was not applicable to her work as an administrative assistant.

In contrast, two participants had more mixed responses, both suggesting modifications of the AR device to make it easier to use. The participant who works as an engineering lab assistant commented, “If the technology advances, yes, otherwise it is too cumbersome.” The graduate student who is currently working in a manufacturing plant also mentioned potential intergenerational differences: “The technology is great, but I think it could be adopted better if it was a bit smaller on the head. A lot of older folk work where I work and I can’t see them using something like this versus being handed a document and figuring it out. Younger folk would probably gravitate to this more.”

VI. Discussion and future work

This research was joint work by graduate and undergraduate students from two Universities, the University of Akron (UA) and the University of Massachusetts Lowell (UML). The AR experiments with the conveyor system originated in the doctoral thesis [15] of one of the graduate students from UA. Extensions to this system (scenarios designed for the participants in the PAR focus groups) were developed at UML during a summer research activity wherein the

PhD student from UA introduced key concepts of the NCARS framework to four students (2 graduate, 2 undergraduate) at UML. The group was supervised by three faculty members from engineering and social-science disciplines. This team co-created an AR-assisted guidance of the basic operation of the conveyor system for those who did not have any prior experience with this system. Moreover, the goal was to enable them to operate the system without any assistance from a member of the research group.

The PAR focus groups conducted before and after the experiments with the conveyor system generated multiple concerns and recommendations from the users that had not been considered by the system developers. This includes, for example, the safety/comfort of using AR devices, the location of the physical experiment itself and the discomfort in conducting the experiment while standing. One of the concerns which was related to blurriness when participants used the AR device, was addressed by including an eye calibration step prior to the AR-assisted task experiment. In general, the range of recommendations from users who were not familiar with the device and those with some degree of familiarity were found to be important additions for the system developers to integrate into the next version of this experiment. Of particular interest, is automating some elements of the PAR process within the NCARS framework so that users can be prompted to provide recommendations for improvement while they are using the system, thus engaging users as co-creators of an improved system.

VII. Conclusions

Augmented Reality (AR) devices that are integrated into effective training and education systems are very likely to have a significant role in shaping the future of work in a broad spectrum of areas. The current approach to developing AR applications for these activities is limiting, tedious, error prone, and technically challenging. The effectiveness of an AR system for training and education depends critically on the AR content and not on the technical novelties of the system. Such AR content must be developed by a multi-disciplinary authoring team. However, the technical challenges and idioms of the game engines preclude full participation by such a team.

The AR systems framework described in this paper offers a new, robust, and scalable approach to creating AR content. By supporting four key activities – annotation, guidance, navigation, and safety – the framework enables a multi-disciplinary authoring team to create effective AR content using familiar software tools. When such content is packaged into Immersive Action Units (IAU), the framework can deliver sequences of IAUs to effectively engage the users.

This paper also demonstrated the value of participatory action research (PAR) in the development of such systems that impact the future of work. PAR offered a methodological approach to effectively engage users as potential co-creators of AR content. The multi-disciplinary authoring framework proposed enables the quick curation and update of the AR contents based on feedback from the users.

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