Improving workforce development initiatives using augmented reality technology

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ABSTRACT

The National Shipbuilding Research Program (NSRP) is an organization whose mission is to combine U.S. shipbuilding and repair research and development funding to decrease the total cost of ownership for the U.S. Navy. The goal of this NSRP project was to demonstrate effective use of augmented reality (AR) in the industrial environment for skill-based and knowledge acquisition learning. The AR applications developed in this project provided equipment 3D representation, step-by-step guidance and safety information where applicable. The NSRP project team developed both the instructional strategy and tablet/head-mounted display applications, and also conducted pilots and usability studies for each application that provided measurable data to support the use of AR. Five AR applications were developed as part of this project. Two applications were specific to Huntington Ingalls Industries shipbuilding Apprentice School courses, and three were specific to shipbuilding operational training. As of the writing of this paper, it appears that AR technology improved workforce development initiatives and can serve as an effective training and job aid. This paper shares overall details of the NSRP project, to include a basis by which instructional designers can incorporate AR technology into similar workforce development initiatives.

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INTRODUCTION

The National Shipbuilding Research Program (NSRP) is an organization whose mission is to combine U.S. shipbuilding and repair research and development funding to decrease the total cost of ownership for the U.S. Navy (National Shipbuilding Research Program, 2019). The goal of this NSRP project was to demonstrate effective use of augmented reality (AR) in the industrial environment for skill-based and knowledge-acquisition learning.

The NSRP project team developed both the instructional design, learning activities and tablet/head-mounted display AR applications, and also conducted pilots/usability studies that provided measurable data to support the use of AR. Five AR applications were developed as part of this project. Two applications were specific to Huntington Ingalls Industries' shipbuilding Apprentice School courses, and three were specific to shipbuilding operational training. All AR applications combined, real and virtual, were interactive in real time, and registered in a 3D virtual environment. Learning activities for all applications were aligned with each learning objective and segmented into immersion, interaction and engagement categories. This paper shares overall details of the NSRP project to include a basis by which instructional designers can incorporate AR technology into similar workforce development initiatives.

AUGMENTED REALITY INSTRUCTIONAL DESIGN

AR transposes virtual images over reality. When tested on manual assembly tasks, previous research indicates that AR can be helpful by increasing assembly time, resulting in fewer errors and mental workload (Hou, Wang, & Truijens, 2015). The researchers concluded that AR decreased labor by 50% (Hou, Wang, & Truijens, 2015). This high percentage clearly justifies the motivation toward using AR technology but does not speak to how the technology should be designed to enrich learning. The project team focused on containing three basic features and categories, as well as ensuring that learning activities were appropriately aligned to learning objectives.

The objective of the AR applications were to improve learning through the use of AR technology. Each application contained three basic AR features (Azuma, 1997):

- AR combines real and virtual.
- AR is interactive in real time.
- AR is registered in 3D environment.

Research tells us that AR is an effective cognitive tool for learning when applications are generalized into three categories (Trindade, Fiolhais, & Almeida, 2002):

1. Immersion - visualized as intangible to the real world, enabling learners to experience educational elements within a transposed virtual environment.
2. Interaction - learners are no longer passive observers but instead serve as active demonstrators who experience objects within a virtual environment.
3. Engagement - learners can independently control elements within virtual environment.

Learning activities were aligned with each learning objective and segmented into immersion, interaction and engagement categories. The instructional strategy included three characteristics for each AR application: (1) the application enabled and then challenged the student, (2) allowed for a game-based philosophy when logical, and (3) displayed a virtual environment that could not be visualized in the real world (Dunleavy, 2014).

Table 2 identifies additional instructional design strategies based on a few of Gagné's (1992) events of instruction.

Table 1: Additional instructional design strategies

Instructional Design Strategy	Reasoning
Inform objectives	Students were able to use objectives as a point of reference by which to gauge success. The instructor identified objectives before the student began the AR-assisted task.
Present Content	All demonstrations included detailed explanations to provide more comprehensive instruction. Students had the choice to view a video demonstration as guidance toward task completion when logical.
Learning Guidance	Applications contained various instructional prompts to help the student successfully complete the AR-assisted task.
Elicit performance	Students had an opportunity to practice newly learned skills through AR-guided interaction when logical.
Technology-based Delivery	Performance was enhanced through the use of AR-based guidance.
Enhance retention and transfer to the job	Students performed newly learned skills/knowledge in a virtual environment.
Reduce Cognitive Load	Learners were allowed interactivity by having the choice to acquire more information on specific topics.

Instructional Design Theories

The primary instructional design theory of these AR applications will be based on a constructivist philosophy of learning. Constructivism assumes that students create meaning of what is being learned by constructing new information built on previous knowledge (Delello, McWhorter, & Camp, 2015). The constructivist theory is specific to the context in which learning occurs (Duffy & Jonassen, 1991), and that learning is only achieved by completing meaningful learning activities (Brown, Collins, & Duguid, 1989). Constructivist theory assumes the learner is clearly aware of the required learning objectives and activities (White & Safadel, 2016).

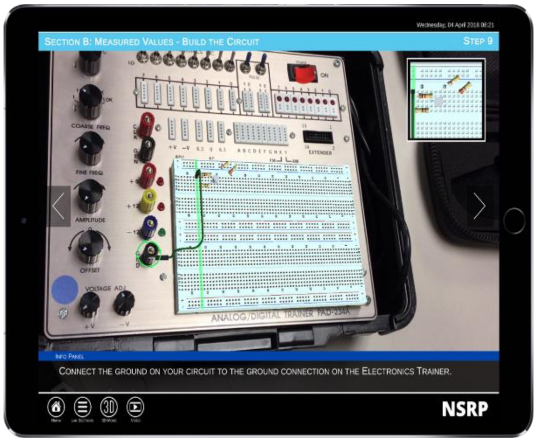
Situated learning theory will serve as a secondary theory in that it speaks to the context in which learning occurs (Brown, Collins, & Duguid, 1989). In addition, situated learning assumes that the learner is actively engaged in their own learning by tapping knowledge gained in an authentic environment (Clarkson, 2014). Learning will be situated through the use of AR that will be transposed over the student's "authentic environment." As previously mentioned, AR has two elements of realism by being displayed in "real time" and transposed over the "real world." (Azuma, 1997)

Table 2 identifies the AR application, learning objectives and target audience for each application.

Table 2.AR applications and learning objectives

AR Application	Learning Objectives	Target Audiences
#1: Solid State and Devices	Upon successful completion of this application, learners will be able to: • Demonstrate how to build a circuit • Demonstrate how to supply power from an adjustable source • Demonstrate how to measure voltages • Demonstrate how to "break a circuit" and measure currents.	The target audience will consist of: • New Apprentice School students, • Newly hired and/or existing inexperienced shipbuilding, and

AR Application	Learning Objectives	Target Audiences
		• Repair tradespeople who will have electrical job requirements.
#2: Absence of Voltage (AOV)	Upon successful completion of this application, learners will be able to: • Verify the tag(s) is hung in accordance with the tag(s) called out on work permit, work authorization, tag-out, red tag log and confirm the device position as stated on tag. • Verify name plate data on equipment to be checked. • Confirm that the multimeter is properly calibrated. • Visually inspect meter for any damage (including leads). • Establish a ground with less than 10 ohms resistance to the ship's hull. • Check all connections to ground reference point for voltage. Check phase-to-phase if applicable. (A/C). • Check all connections to ground reference point for voltage. Check all circuits negative to positive (D/C). • Identify appropriate actions when presented with various electrical anomalies.	The target audience for this recertification are certified electricians and engineers who are responsible for either performing or observing AOV duties.
#3: Aerial Lift Operator Training	Upon successful completion of this application, learners will be able to: • Identify aerial lift safety/ODCL requirements • Demonstrate requirements for operating an aerial lift • Demonstrate correct actions for aerial lift shutdown, and breakdown/accident reporting.	The target audience will consist of: • Newly hired shipbuilding JLG operators, and • Existing JLG operators who are scheduled for requalification.
#4: Flange Make-up	Upon successful completion of this application, learners will be able to: • Identify flange types • Demonstrate the proper process of flange joint assembly • Demonstrate the process of applying torque to threaded fasteners.	The target audience will consist of: • Newly hired shipbuilding machinists, and • Existing trade-specific workforce transitioning/cross-training for flange make-up.
#5: Ship Construction	Upon successful completion of using this application, learners will be able to: • Define basic ship structure terminology • Identify major structural hull components	The target audience will consist of: • Shipbuilding apprentices, and • Newly hired shipbuilding employees



APPLICATION ONE

Electricians master the techniques involved in the layout, installation, hookup and testing of every electrical system aboard ship. As today's modern warship becomes more dependent on its technological infrastructure, the skill and expertise of electricians tasked with its construction is of vital importance. The target curriculum and associated courses for this application were specifically for marine electricians and Basic Electrical Theory apprentices. According to grade metrics from the Solid State Device and Circuit course, electrical apprentices received overall grades no higher than 75. Labs six and seven of the course were identified by instructors as being particularly troublesome for students. These lab exercises focused on building and breaking specific circuits with minimal guidance and testing. As these labs were considered foundational to the overall understanding of electrical theory, student comprehension during this point of learning was critical to building knowledge in the discipline. The AR application transposed instructional step-by-step guidance directly over the electrical training board to aid the learner while completing the lab exercises.

The learning objectives for this AR application were:

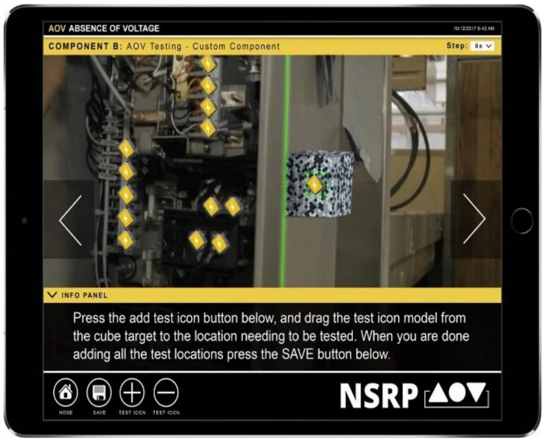
- Demonstrate how to build a circuit
- Demonstrate how to supply power from an adjustable source
- Demonstrate how to measure voltages
- Demonstrate how to "break a circuit" and measure currents**.**

The target audience for this AR application consisted of:

- New Apprentice School students,
- Newly hired and/or existing inexperienced shipbuilding, and
- Repair tradespeople who will have electrical job requirements.

The intention of this AR training application was to supplement existing training material, improve corresponding chapter test scores, decrease student time to complete both labs and increase student engagement. Based on research, a SUS score above 68 would be considered above average and anything below 68 is below average (Brooke, 2006). The system usability scale (SUS) baseline usability score for this application was 83.75 and final usability score was 85.8, showing a 2.05 increase in usability.

The AR application was piloted with actual apprentices who were currently enrolled in the course while completing labs six and seven. As previously mentioned, according to grade metrics from the Solid State Device and Circuit course, electrical apprentices received overall grades no higher than 75. When comparing pilot participant overall AR-assisted grades, 50% scored higher than a score of 75. Pilot test scores, usability results, instructor and student feedback suggests that the AR application did enhance learning.



APPLICATION TWO

The project team performed a gap analysis and identified consistent performance problems regarding Absence of Voltage (AOV) recertification. The analysis included discussion with both the electrical and training delivery organizations.

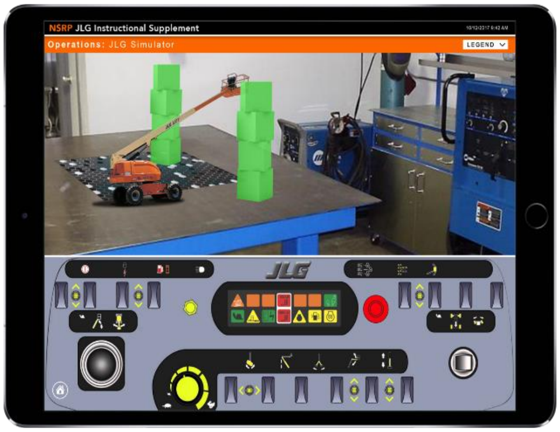
The electrical team shared that initial AOV qualification is received by the shipbuilder after successfully completing an introductory AOV training course. The qualification expires after two years, at which time the shipbuilder is required to complete a recertification "practical." The recertification process required the shipbuilder to complete a standard 10-step procedure-based process that was observed/graded by a certified instructor. If the shipbuilder missed one step while performing the procedure, their certification was revoked and they were required to attend the initial training course. Prior to attending the recertification, the shipbuilder's foreman reviewed and discussed the AOV steps, watched and reviewed an AOV process video and administered a refresher questionnaire with the shipbuilder. Unfortunately, this effort did not result in a significant impact toward performance improvement. When considering the high "unsuccessful" rate (26%) for recertification, the electrical team indicated that the AOV process was often an infrequently used procedure during the shipbuilder's two-year qualification period.

The overall AOV process was also complicated by the wide variety of shipboard components used to determine absence of voltage. The electrical team indicated that selecting two frequently used components could serve as an initial application. Users would be presented with menu options to select one of two components (Power Panel and Distribution Box). Simplistic component representations (to accommodate varied component models) could be used as the AR target. The user would then be guided via AR technology while at the same time presented with the 10-step procedure. As the AOV recertification was infrequently performed by electrical personnel, this AR application would also serve as a pre-certification refresher that is administered on a routine basis.

The training delivery organization shared with the project team that an instructor teaches the initial AOV qualification course and administers the AOV recertification process. The delivery organization indicated that a large portion of the workforce did not understand AOV theory and were unable to determine the correct steps required on specific electrical components. Therefore, a job aid that provided theory-based guidance would be beneficial toward improving workforce development. The instructor walks the tradesperson through the 10-step process prior to recertification, but the information was often forgotten before the actual practical, which occurred immediately after the refresher session. An AR job aid would serve as a refresher at any point in time to refresh the step-by-step process, as well as allow for repetitive drilling to aid knowledge retention.

The intention of this AR application was to improve AOV recertification performance, improve AOV knowledge retention and increase task engagement. The SUS baseline usability score for this application was 80.75 and final usability score was 71.25, showing a 9.5 decrease in usability. The decrease in usability may have been attributable to the difference between baseline and final usability participants, as it relates to the experience level with AR. When asked to rate their experience level with AR, baseline participants reported an average of 1.6 while final usability participants reported an average of 1.5 on a scale of one to five; one being no experience and five being an expert.

A pilot was conducted using shipbuilders who were scheduled for recertification. These shipbuilders completed the recertification as previously administered, except the refresher involved use of the AR application. The resulting pass rate increased from 74% to 100%, which indicates that AR did improve workforce development.



APPLICATION THREE

JLG Industries is a designer and manufacturer of equipment that can safely and quickly lift workers in the air to perform construction and maintenance functions (JLG Industries, 2018). The goal of aerial lift training was to prepare new operators to begin on-the-job training (OJT) with a qualified operator. New operators learn the required steps for preparing the aerial lift for operations, including completion of the Operator's Daily Checklist (ODCL), safety precautions during operations, and steps for shutting down and securing the equipment.

Aerial lift qualification began with a four-hour "operator's" course, which is followed by a proctored written test. Once the operator course was successfully completed, development was continued with a 6-month OJT with a qualified operator. During the 6-month OJT, the operator was able to complete an observer-based qualification as many times as needed until qualification was achieved. The initial qualification expired after three years, at which time the operator was required to complete the requalification process. The requalification process included the following:

- A requalification requirement notification was sent to the foreman two weeks before the month requalification was needed.
- The foreman contacted the qualifying department to schedule the requalification.
- During requalification, the qualifier observed and documented the operator's actions. (The typical requalification could take up to two hours.)
- If the operator was unsuccessful with any one task listed on the ODCL, the operator's qualification was revoked.
- If the operator's qualification was revoked, they were required to remediate back to initial aerial lift operator training, and successfully complete the written test as well as the six-month OJT to attain requalification.

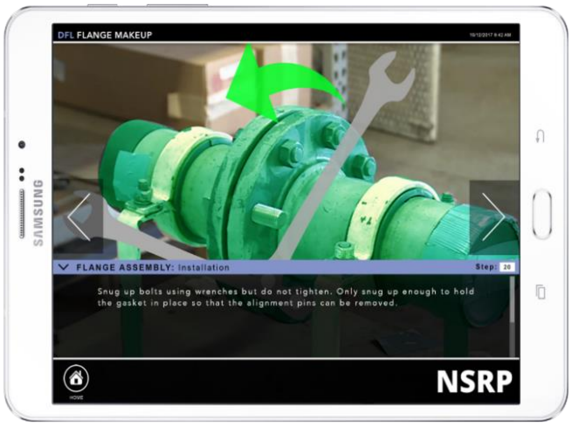
In addition to qualification requirements, aerial lift operators were also required to complete an ODCL before physically operating the aerial lift. The checklist began with a pre-operational check (e.g. operating fluids), then operational checks from the ground, and finally operational checks from platform controls. Any unsatisfactory item identified on the checklist was to be reported to the supervisor immediately, and if it was a safety item, the machine would be declared inoperable pending further investigation.

The project team performed a gap analysis and identified consistent performance problems regarding requalification. The analysis included discussion with aerial lift operators and internal training delivery departments. A customized learning management system report revealed a 68% "unsuccessful" requalification rate of completion.

Using a game-based methodology, the intention of this AR application was to serve as a training and job performance aid that would familiarize new aerial lift operators with operational components of aerial lift equipment and refresh existing operators before requalification. The application involved a visual representation of the control panel that simulated actual functions of the equipment. Users were provided with various tasks to accomplish and provided success/failure feedback.

The SUS baseline usability score for this application was 90 and the final usability score was 78.5, showing an 11.5 decrease in usability. The SUS decrease could be attributed to the participant's level of comfort with new technology. When asked to rate their comfort level with new technologies, baseline participants reported an average of 5 while final usability participants reported an average of 4.2 on a scale of one to five; one being "not comfortable at all" and five being "very comfortable."

A pilot was conducted using shipbuilders who were scheduled for requalification. These shipbuilders completed the requalification as previously administered except the refresher involved incorporated use of the AR application. The requalification pass rate increased from 32% to 75%, indicating that AR did improve workforce development.



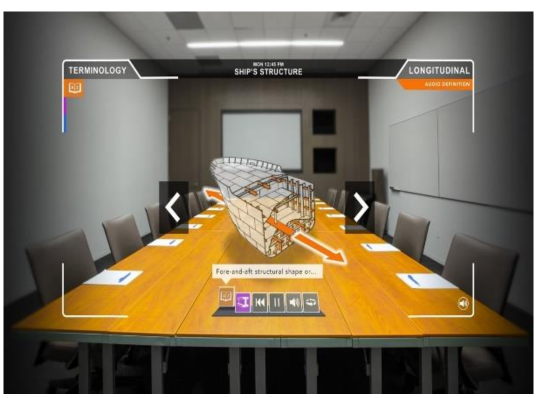
APPLICATION FOUR

Flanges are used throughout a ship to mechanically join two pieces of equipment into one with the combined use of fasteners. They are installed to allow quick and easy removal of piping and equipment for access or repair. Flange make-up is one of the most demanding installations performed by outside machinists. The installation itself is not difficult, but the process contains very precise and detailed installation procedures that must be closely followed. Current flange make-up training currently involves hands-on instruction with instructor-led guidance.

Flange joints consist of two piping or ventilation flanges held together by fasteners (nuts, bolts, studs, hex head cap screws or a combination thereof) to provide portability of sections of piping/ventilation, facilitate testing, or allow for removal of piping/ventilation components for repair or maintenance. Flanges may be individual fittings welded or brazed on one end and flanged on the other, or incorporated into the design of valves, filters, strainers, elbows, tees, etc. Flanges are typically sealed by a gasket or O-ring seal to prevent leakage. Flanged joints may also encapsulate components, such as orifice plates or spectacle flanges. Flanges may be round, square or rectangular in shape. Flange joints typically require significant access space to allow for their tightening and loosening and for removal of the fasteners themselves.

By conducting a performance analysis of outside machinists, the project team found that flange makeup is one of the most prominent quality risks. While metrics do not show internal failures occurring in the classroom, there are external failures occurring on the product line and on the deck plate. During an outside machinist's pre-hire program, the instructor indicated a first attempt 90% "unsuccessful" rate when completing the practical exam. However, students are allowed multiple attempts in the classroom until the process is performed correctly. The longer it takes the student to successfully complete the practical, the more labor cost will be attributed to training. Achieving success on the first attempt would greatly decrease the overall cost of training.

The intention of this AR application was to serves as a training aid to help students; identify flange types, demonstrate the proper process of flange joint assembly, demonstrate the process of applying torque to threaded fasteners. The AR application transposed step-by-step guidance toward assembling a flange, as well as specific notes regarding tips and tricks to accomplish the specific task. Usability and pilot results were unavailable as of the writing of this paper but will be presented to conference attendees.



APPLICATION FIVE

The concept of offering ship design courses to newly hired shipyard workers and shipyard apprentices is to provide a basic understanding of naval and commercial ship engineering and operating systems. Knowledge acquired during foundational shipbuilding courses affords apprentices and new hires more opportunity to apply critical thinking skills during the performance of their specific duties. During standard ship design courses, learners are required to develop a mental model of shipboard components via print, video or computer screen. If there is a vessel nearby, learners may have the opportunity to tour various ships, but internal ship structural components are frequently behind shipboard equipment and invisible. Learners can now view ship structure by examining a 3D virtual representation which allows them to develop a better understanding of ship design.

Understanding complex systems takes a longer period of time when the learner is left to their own imagination. Learners often lack the visualization skills to interpret abstract physical concepts (Balta, 2015). Oftentimes what is needed is a means by which to virtually visualize the concept or product. The virtual holography aspects of AR allow the user to view virtually displayed 3D objects. Learning using a 3D virtual holography display will result in faster performance as opposed to learning with a 2D display (Aras, Shen, & Noor, 2014), such as print.

The Apprentice School at Newport News Shipbuilding offers a foundational Ship Construction I course that could be enhanced with AR technology. This course is focused on ship history, ship structure, ship terminology, naval information and shipyard information. AR technology could be delivered as part of "lab-like" exercises associated with various lessons within this larger course.

There are 14 lessons, two tests, quizzes, writing and homework assignments in the Ship Construction I course. The scores from these assignments serve as good historical data on which to evaluate the effectiveness of a redesigned course using AR technology. A customized report from the learning management system indicated a 8.2% course unsuccessful rate in 2018 that was higher than the 2017 3.47% unsuccessful rate. Apprentice School instructors indicated that students have a difficult time understanding ship structure.

Previous project applications made use of tablet-based technology, but this particular AR application is specific to a head-mounted display device. The justification for selecting this device solution was based on activity theory. Activity theory is specific to human activities and then realized through goal-oriented actions within certain environments (Zhu & Mitchell, 2012). Activity theory believes that learning cannot be separated from activity and the activity is mediated by learning tools (Said, et al., 2014). For example, research has found that learners have mixed motivations that are triggered and maintained through the use of technology (Jin & Zhu, 2010). New apprentices and hires will be intrigued with completing activities presented in a 3D holographic environment and will be more motivated/attentive to the information conveyed.

The intention of this AR application was to serve as a training aid to help students; define basic ship structure terminology, identify major structural hull components, identify the differences between the transverse framing, longitudinal framing, and combination/cellular framing. Usability and pilot results were unavailable as of the writing of this paper but will be presented to conference attendees.

CONCLUSION

As of the writing of this paper it appears that AR improved workforce development initiatives and can serve as an effective training and job aid. Application one supplemented lab exercise information by transposing step-by-step guidance over an electrical trainer. The intention of this AR training application was to supplement existing training material, improve corresponding chapter test scores, decrease student time to complete both labs, and increase student engagement. Test scores were 50% higher than test scores from the previous semester, indicating that AR did improve workforce development. Application two served as a training aid for existing electricians with absence of voltage responsibilities. The recertification pass rate increased from 74% to 100%, indicating that AR did improve workforce development. Application three served as a training and job performance aid that will familiarize new JLG operators with operational components of JLG equipment and refresh existing JLG operators before requalification. The requalification pass rate increased from 32% to 75%, indicating that AR did improve workforce development. Application four was a training aid for flange make-up training and application five was an Apprentice School ship construction course. Usability and pilot results from applications four and five were not available as of the writing of this paper.

ACKNOWLEDGEMENTS

The NSRP project team would like to acknowledge the hard work of all project members, study participants and organizational support for this effort. It takes a multidisciplinary team of individuals to complete the tasks involved with this project and, at times, the challenges seemed unsurmountable. As a team, the work was completed to the benefit of Newport News Shipbuilding and the shipbuilding industry.

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