*Proceedings of 5th International Conference CNDGS'2026*
ISSN 2669-2023 (print) / ISSN 2538-8959 (on-line) / **https://doi.org/10.47459/cndcgs.2026.39**

# Using Virtual Reality and AI to Teach the Historical Role of Artillery in Warfare

**Natálie GOTTVALDOVÁ[1]*, Martin BLAHA[1], Daniel KOREC[1], Markéta MACHOVÁ[2]**

*[1] Department, Faculty, University of Defence, Kounicova 65, 662 10 Brno, Czech Republic*
*[2] XR Unity Developer, YORD Studio s.r.o., Prague, Czech Republic*

*Correspondence:* natalie.gottvaldova@unob.cz*

**Abstract**

This paper examines the use of Virtual Reality (VR) for teaching the historical role of artillery. The methodology combines VR-based scenarios with behavioral and speech analytics supported by Artificial Intelligence. The findings indicate that VR enhances understanding of decision-making under constraints and shifts learners from technical to context-driven reasoning. The results suggest that VR can improve the linkage between theory and operational practice in artillery training. The study contributes by integrating experiential learning with measurable performance indicators and offers a novel approach to military education.

**KEY WORDS:** *Virtual Reality; Artificial Intelligence; Artillery History; Military Education; Ballistics; Battlefield Context; Learning Effectiveness*

**Citation:** Gottvaldová, N.; Blaha, M.; Korec, D.; Machová, M. Using Virtual Reality and AI to Teach the Historical Role of Artillery in Warfare. In Proceedings of the Challenges to National Defence in Contemporary Geopolitical Situation, Brno, Czech Republic, 7-10 September 2026. ISSN 2538-8959, https://doi.org/ 10.47459/cndcgs.2026.39

## 1. Introduction

Traditional frontal instruction has long been a dominant method in military education; however, its effectiveness for contemporary learners is increasingly limited [5], [6]. This limitation becomes particularly evident in domains that require the integration of technical knowledge, situational awareness, and decision-making under uncertainty [9], [10]. Artillery operations represent a typical example of such domains, as they inherently combine technical procedures with context-dependent decision processes. In the context of teaching artillery history, these limitations become even more pronounced. Instruction is frequently reduced to descriptive narratives, chronological timelines, and isolated technical facts. While such approaches provide basic factual knowledge, they do not sufficiently explain the operational significance of artillery employment. In particular, they fail to clarify the rationale behind command decisions or the constraints under which historical actors operated. As a result, learners often acquire fragmented knowledge that lacks contextual depth and analytical applicability. This issue is closely related to how artillery history is conceptualized. It is often presented as a static record of weapons systems and firepower development, rather than as a dynamic interaction between technology, doctrine, terrain, command structures, and uncertainty. Such a reductionist interpretation obscures the role of artillery as a command instrument.

Consequently, learners may know what occurred in a given historical engagement, but they frequently lack insight into why specific decisions were made, how limitations in observation and communication shaped outcomes, and why alternative courses of action were not feasible. This gap reflects a broader methodological problem. Traditional instructional approaches are insufficient for conveying the decision-driven nature of artillery employment. Understanding artillery in historical warfare requires more than the transmission of facts; it requires the reconstruction of context, constraints, and decision-making processes [11]. Without this reconstruction, knowledge remains descriptive rather than operational. In this context, Virtual Reality (VR) can be understood as a methodologically grounded approach to addressing these limitations [13], [17]. Its relevance does not lie only in visualization, but in its ability to support immersive, scenario-based learning environments [14]. Within such environments, learners can be placed directly into historically grounded operational contexts. They are then required to engage with incomplete information, constrained communication, terrain limitations, and doctrinal restrictions—conditions that closely resemble those faced by historical commanders [15,16].

This shift is important because it changes the nature of learning. Instead of focusing on procedural correctness alone, learners are required to interpret situations and make decisions under uncertainty. In this sense, VR supports the representation of decision-making processes rather than only the presentation of historical facts. The primary objective of this study is therefore to define and justify the use of VR as a tool for teaching the historical role of artillery. The study further aims to propose a structured instructional framework based on VR scenarios and to establish measurable indicators for evaluating learning effectiveness. In addition, the role of Artificial Intelligence (AI), particularly Large Language Models (LLMs), is examined as a supporting component for adaptive instruction and structured analytical reflection [6], [27].

## 2. Methodology

The research methodology is based on the integration of VR-supported scenario-based learning, historical analysis, and learning analytics [18], [19]. Rather than relying on generic or purely technology-driven simulations, the approach focuses on the development of historically grounded scenarios that reflect specific doctrinal frameworks, technological limitations [1], [24], and operational contexts of artillery employment [3]. Each scenario represents a concrete historical situation in which artillery played a decisive or illustrative role. The design process emphasizes the accurate representation of operational constraints, including limited observation capabilities, restricted communication channels, delayed execution of fire missions, and doctrinal rigidity. These constraints are not treated as secondary elements; they are essential for preserving historical fidelity and ensuring that the learning experience reflects the actual conditions under which decisions were made.

The instructional process is structured into three interconnected phases. The preparatory phase introduces learners to the historical context, including the operational situation, doctrinal assumptions, available resources, and mission objectives, thereby establishing the theoretical foundation and clarifying the constraints and intent associated with the scenario. The immersive phase takes place within the VR environment, where learners are placed in a simulated battlefield context and interact with terrain, command relationships, and fire support systems under historically accurate limitations. This phase deliberately emphasizes decision-making under uncertainty rather than procedural correctness [9,20], requiring learners to interpret incomplete information, prioritize tasks, and adapt to evolving conditions. The final phase consists of a structured debriefing, which is essential for transforming experience into learning [12]. During this phase, learner decisions are systematically compared with documented historical outcomes, with emphasis on discrepancies between intended and actual effects, the influence of constraints, and the internal coherence of decision-making processes.

Artificial Intelligence is integrated into the methodology as a supporting component rather than a primary decision-making tool. LLM-based systems are used to provide contextual prompts, support adaptive questioning, and structure after-action reviews [6, 27]. In parallel, AI tools are employed to collect and process behavioral data generated during the VR experience. To ensure that evaluation is not limited to subjective impressions, the methodology incorporates measurable indicators of learner performance. These include decision latency, interaction patterns, adaptation to uncertainty, and selected communication characteristics. These indicators establish a data-driven basis for evaluating the effectiveness of VR-supported instruction in comparison with traditional methods. The pilot implementation involved a total of 24 participants drawn from a military education environment. The cohort consisted primarily of students and early-career officers with a background in artillery or related combat support domains. Participants had prior exposure to basic fire control procedures and command principles but limited experience with immersive simulation tools.

The intervention was conducted through a series of structured sessions, each lasting approximately 60–90 minutes. Participants engaged with 2–3 VR-based scenarios representing distinct historical situations with varying levels of complexity and constraint. Data collection combined automated behavioral logging within the VR environment with structured observation during scenario execution and debriefing. Recorded variables included decision latency, interaction patterns, and selected communication characteristics. In addition, qualitative data were obtained through guided debriefing sessions. Given the exploratory nature of the study, no formal control group or direct comparison with traditional instruction was implemented at this stage. The primary objective was to assess the feasibility of the approach and to identify initial patterns in learner behavior,

### 2.1 Artillery as a decision-centric system rather than a purely technical domain

Modern artillery cannot be adequately understood as a purely technical system defined only by ballistic accuracy, range, or firepower. Instead, its effectiveness emerges from the interaction between sensing, command and control (C2), decision-making, and execution under constraints. This perspective is supported by research emphasizing the central role of human operators and decision processes even in technologically advanced systems [31,49,50].
In practical terms, artillery performance is rarely limited by computational capability alone. More often, it is constrained by incomplete information, delays in observation and communication, and the need to integrate fires within a broader operational framework. These factors directly affect how fire missions are planned and executed.

This shift in perspective is critical for the present study. It reframes artillery from a domain focused on procedural correctness to a decision-centric system in which technical solutions must be evaluated in relation to timing, intent, and operational context. From an educational standpoint, this implies that teaching artillery—particularly its historical dimension—requires approaches capable of representing decision-making under constraints rather than only transmitting technical knowledge. This requirement is further reinforced by interoperability challenges in joint fires and multinational operations.

Differences in procedures, communication structures, and doctrinal approaches introduce additional layers of complexity, which must be reflected in both analysis and training [30].

### 2.2 Constraints, uncertainty, and supporting functions in artillery operations

Building on the previous section, a second relevant research strand focuses on the role of supporting functions and environmental constraints in shaping artillery outcomes. Elements such as meteorological data, terrain representation, and observation capabilities are not auxiliary; they directly influence the feasibility and effectiveness of fire missions. Empirical and technical studies show that artillery frequently operates under degraded data conditions, where estimation and approximation replace precise measurement [37]. This has direct implications for decision-making, as uncertainty becomes an inherent part of the process rather than an exception.

Similarly, research on terrain modeling, remote sensing, and fire effectiveness highlights the importance of integrating multiple data sources into a coherent operational picture. This includes the use of unmanned systems for artillery survey and sensing, as well as advanced data acquisition methods such as LiDAR or multispectral detection [27,39,43,45]. Recent studies further demonstrate that artillery-related methods are applied beyond traditional combat contexts. Examples include environmental assessment of impact zones and wildfire suppression, which illustrate how artillery operates within complex and constraint-driven environments [28,29].

From a methodological perspective, these findings are directly relevant to training design. Instructional environments that omit uncertainty, delays, or imperfect information risk producing fundamentally incorrect mental models. Therefore, the inclusion of such constraints is not optional but necessary for maintaining operational validity.

### 2.3 Simulation, VR, and experiential learning in military education

Simulation has long been used in military training for procedural rehearsal and analytical purposes. However, traditional simulation environments often prioritize technical correctness and repeatability, sometimes at the expense of experiential understanding. In contrast, Virtual Reality introduces a different approach. It enables immersive, scenario-based learning in which users actively engage with complex environments. In military education, simulation remains a key enabler not only for training but also for research and capability development [41,44]. Constructive and analytical simulations have been used to evaluate fire unit effectiveness, survivability, and tactical behavior under controlled conditions [32,44]. While these approaches are valuable, they typically focus on system-level performance rather than on the experiential dimension of decision-making.

For artillery training, this distinction is particularly important. Historical artillery employment cannot be meaningfully understood without considering limitations in observation, communication delays, doctrinal constraints, and terrain effects. VR provides a controlled environment in which these factors can be explicitly represented and systematically manipulated. The present study builds on this premise. VR is not used merely as a visualization tool, but as a medium for reconstructing decision-making contexts. This approach aligns with experiential learning theory, where knowledge is formed through the transformation of experience into structured understanding [11].

### 2.4 Artificial Intelligence and data-driven evaluation of decision-making

Another relevant area concerns the application of Artificial Intelligence in military decision-support and training systems. Existing approaches demonstrate the use of AI for optimization, planning, and evaluation under uncertainty, including algorithmic methods and resource allocation models [33,35,47]. However, these approaches are typically oriented toward system-level performance. They focus on optimizing outcomes rather than analyzing the behavior of individual operators. Recent developments indicate a shift toward process-oriented evaluation, where attention is directed to how decisions are made rather than only to their results. This shift is particularly relevant in artillery contexts. A technically correct fire solution does not guarantee operational effectiveness, especially under conditions of uncertainty, delay, and incomplete information. Data-driven analysis enables these discrepancies to be identified and systematically evaluated.

One example of this trend is the use of AI-supported speech-to-text systems in artillery command environments, where AI assists in processing and structuring information within fire control workflows [31]. Such applications demonstrate that AI can support, rather than replace, human decision-making. The integration of speech-based indicators represents a further extension of this approach. Verbal expression provides indirect insight into cognitive processes such as uncertainty, confidence, and reasoning structure. Although these indicators must be interpreted cautiously, they offer an additional analytical layer that is not accessible through traditional evaluation methods.

### 2.5 Gap in current research and relevance for the present study

Existing research provides substantial coverage of several relevant areas. These include technical aspects of artillery fire control, supporting functions such as meteorology, sensing, and terrain modeling, simulation and VR applications in military training, and AI-based decision-support methods. Each of these domains is well developed in isolation and contributes valuable insights into specific components of artillery systems and military education. However, these research strands remain largely fragmented. Technical studies primarily focus on system performance and accuracy, while research on supporting functions addresses data acquisition and environmental modeling. Similarly, simulation and VR studies often emphasize technological capabilities or training effectiveness at a general level, without explicitly addressing decision-making under operational constraints. AI-based approaches, in turn, tend to prioritize optimization and system-level efficiency rather than the analysis of human decision processes [38,42].

As a result, there is a lack of integrated approaches that combine these domains into a unified framework. This gap becomes particularly significant in the context of education and training, where understanding artillery requires the ability to connect technical, environmental, and decision-making dimensions. Specifically, existing research does not sufficiently address how to:

- combine historically grounded scenarios with immersive environments,
- systematically incorporate operational constraints such as uncertainty, delays, and limited observation,
- evaluate learner performance using data-driven, process-oriented metrics rather than outcome-based indicators.

This limitation is further highlighted by broader trends in defence research. Increasing emphasis is placed on data-driven analysis of complex systems, including infrastructure reliability, sensing integration, and operational risk assessment [38,42]. Despite this shift, educational applications remain only partially aligned with these developments, particularly in domains where decision-making under constraints is central.

The present study addresses this gap by explicitly linking VR-based experiential learning with AI-supported analysis of decision-making behavior. Unlike existing approaches, it does not treat these components separately. Instead, it integrates them into a single methodological framework focused on reconstructing decision contexts and evaluating how decisions are made under realistic conditions. In doing so, the study moves beyond isolated technological applications. It contributes to a more operationally relevant approach to military education, in which learning is grounded in constraints, context, and measurable decision processes rather than in procedural correctness alone.

## 3. Design and Preliminary Evaluation of VR-Based Artillery Scenarios

The initial stage of the research focuses on the systematic design and preliminary evaluation of VR-based historical artillery scenarios [1,2]. The objective is not to recreate historical battles in full detail, but to construct analytically useful representations of decision-making situations. This distinction is important, as it allows the study to focus on key mechanisms of artillery employment rather than on descriptive reconstruction. Each scenario is developed on the basis of historical sources to ensure alignment with documented operational conditions, doctrinal frameworks, and technological constraints. Instead of modeling entire engagements, the design process deliberately isolates critical decision points. These points represent situations in which artillery employment significantly influenced the course of events [3,27]. This reductionist approach enables controlled analysis of decision-making processes while preserving historical relevance.

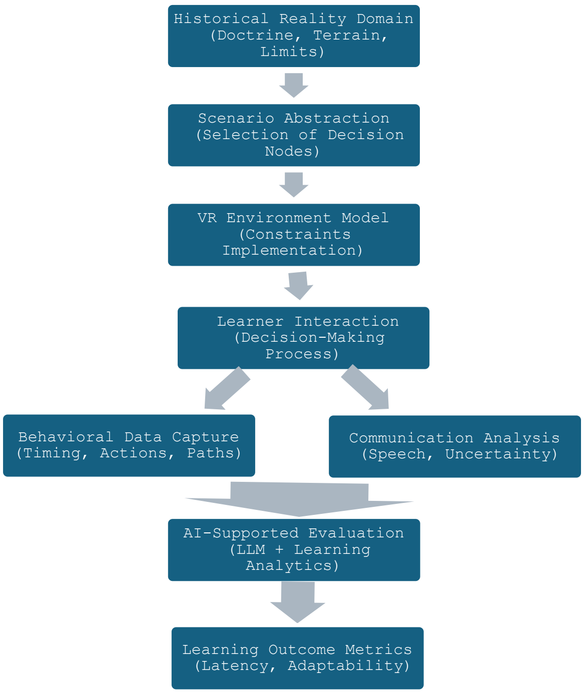


Fig. 1. Framework of VR Scenario Design and Evaluation

A central design principle is the explicit inclusion of operational constraints. These include limited observation capabilities, restricted and delayed communication, temporal gaps between fire request and execution, and doctrinal rigidity. Such constraints are not treated as background conditions but as primary drivers of decision-making. Their inclusion is necessary to avoid simplified or misleading interpretations of historical artillery employment. The overall structure of the approach is illustrated in Figure 1. The framework links historical reality, scenario abstraction, VR implementation, learner interaction, and subsequent evaluation. Importantly, the learning process does not begin in the virtual environment itself. It begins with the transformation of historical reality into a structured and constrained scenario. The framework also highlights a dual-path data collection process, combining behavioral indicators with communication-based data, which are subsequently integrated through AI-supported evaluation.

The preliminary evaluation focuses on measurable indicators that reflect the quality of decision-making rather than the correctness of isolated technical outputs. Traditional assessment methods, based on factual recall or procedural accuracy, are insufficient in this context [8]. Instead, the evaluation framework adopts a process-oriented perspective. Several key indicators are used. Decision latency captures the time required to interpret situational inputs and initiate action. Adaptability reflects the ability to respond to evolving conditions and incomplete information. Coherence represents the alignment between declared intent and executed actions within the scenario. These indicators are complemented by exploratory analysis of communication behavior, which may provide indirect insight into cognitive load and situational certainty.

The relationship between technical correctness and operational effectiveness is conceptualized in Figure 2. The model illustrates that increasing technical accuracy does not lead to a proportional increase in operational effectiveness. Under conditions of uncertainty, limited observation, and delayed execution, even technically optimal solutions may fail to produce meaningful effects. This non-linear relationship constitutes a key learning objective of the VR scenarios, as it challenges the assumption that technical precision alone determines success.

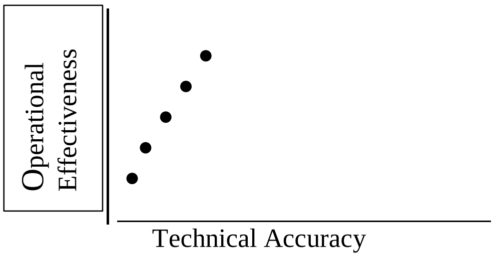


Fig. 2. Non-Linear Relationship Between Technical Accuracy and Operational Effectiveness

The preliminary phase also examines the temporal structure of decision-making within VR environments. Initial observations indicate that delays are not uniformly distributed across the decision cycle. Instead, they are concentrated in phases associated with interpretation and decision-making, where uncertainty and incomplete information have the greatest impact [23].

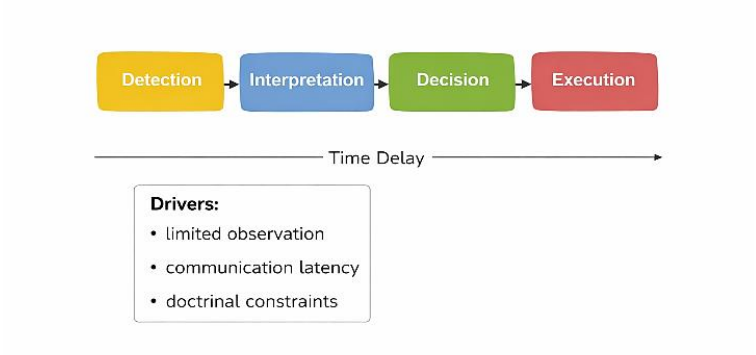


Fig. 3. Temporal Structure of Decision-Making in VR Scenario

This temporal dimension is represented in Figure 3, which divides the decision process into four phases: detection, interpretation, decision, and execution. The model highlights that delays in execution are often driven by external constraints such as communication latency and doctrinal procedures, whereas delays in earlier phases are more closely linked to cognitive processing and situational ambiguity. Although the model remains conceptual, it provides a useful analytical framework for understanding how different types of constraints influence the tempo of decision-making in artillery operations. This perspective is directly relevant for both historical analysis and contemporary training design.

**4. Behavioral and Speech-Based Indicators of Decision-Making**

In addition to standard behavioral metrics, the research incorporates speech-based indicators as a supplementary method for assessing decision-making processes under constrained conditions [18,19]. This approach is based on the assumption that verbal expression can reflect aspects of underlying cognitive processes, particularly in situations characterized by uncertainty and time pressure. Within VR-based artillery scenarios, learners are required to verbalize their reasoning, commands, and situational assessments. These verbal outputs are captured and processed in real time, enabling the extraction of speech-related metrics. Among these, speech fluency—measured as words per minute (WPM)—is used as an auxiliary indicator potentially related to cognitive load and decision hesitation [9].

Figure 4 presents a representative speech fluency curve recorded during a VR-based scenario. The metric is calculated using a moving time window, which allows the observation of temporal variations in speech rate throughout the scenario. This makes it possible to relate changes in verbal expression to specific phases of the decision-making process.

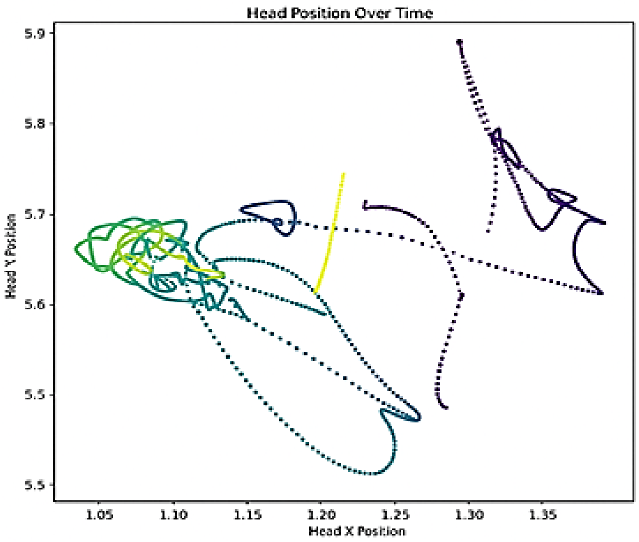


Fig. 4. Fig. 4. Speech fluency curve (Words Per Minute – WPM) over time, calculated using a 30-second moving window

The observed data indicate that speech fluency is not constant. It varies depending on the situational context and phase of the task. Periods characterized by reduced speech rate, prolonged pauses, or abrupt fluctuations often coincide with increased uncertainty, incomplete situational awareness, or the need to reassess available information. Conversely, more stable speech patterns tend to appear in phases where the situation is better understood. However, these relationships must be interpreted with caution. Speech fluency does not provide a direct measure of cognitive load. It can be influenced by multiple factors, including individual communication style, language proficiency, stress response, and familiarity with the task. For this reason, speech-based indicators are not treated as standalone metrics, but as complementary data sources.

From an analytical perspective, the integration of speech metrics extends the evaluation framework beyond observable actions. Behavioral indicators such as decision latency and interaction patterns provide information about what actions were taken and when. In contrast, speech analysis offers indirect insight into how decisions were formed and communicated. This combined approach enables a more nuanced interpretation of performance. For example, a rapid decision may not indicate effective reasoning if it is accompanied by fragmented or inconsistent verbalization. Conversely, a slightly delayed decision supported by structured and coherent communication may reflect a more robust decision-making process. Despite its limitations, the preliminary analysis suggests that speech-based data provide access to dimensions of decision-making that are not captured by traditional evaluation methods. When used in combination with behavioral indicators, they contribute to a more comprehensive assessment of how learners operate under conditions of uncertainty. This is particularly relevant in artillery contexts, where decision quality depends not only on outcomes, but also on the reasoning processes that lead to them.

**5. Design and Preliminary Evaluation of VR-Based Artillery Scenarios**

The preliminary application of VR-based historical artillery scenarios reveals several consistent patterns in learner behavior and understanding. The pilot implementation involved 24 participants, which enabled the extraction of initial quantitative and qualitative indicators. Although the results remain exploratory, they provide an initial basis for evaluating the instructional potential of the proposed approach. One of the most significant observations is the divergence between technically correct solutions and their operational effectiveness. Participants were often able to identify firing solutions that were correct from a computational or procedural perspective. However, these solutions did not always produce meaningful effects within the simulated environment. This discrepancy was primarily associated with constraints embedded in the scenarios, including terrain masking, limited observation, delays in execution, and fragmented command structures.

This finding is further supported by quantitative indicators. Decision latency ranged from 8 to 42 seconds, with an average of approximately 21 seconds across all participants. Longer delays were consistently associated with phases requiring interpretation of incomplete information, while shorter response times were observed during execution phases (Table1).

Table 1. Selected decision-making indicators (n = 24)

| Indicator | Min | Max | Mean |
|---|---|---|---|
| **Decision latency (s)** | 8 | 42 | 21 |
| **Number of decision points per scenario** | 3 | 7 | 5 |
| **Verbal response rate (WPM)** | 82 | 145 | 110 |

These data indicate that technical correctness alone is not a sufficient performance indicator in artillery contexts [7]. Instead, effective decision-making requires the integration of technical knowledge with situational awareness and an understanding of operational constraints. The VR environment makes this relationship directly observable, as learners experience the consequences of their decisions in real time. A second important observation concerns changes in how learners conceptualize artillery employment. At the beginning of the scenarios, participants tend to focus on calculations, firing parameters, and procedural correctness. As the scenario progresses, a shift toward context-dependent reasoning can be observed [13,14]. Learners increasingly consider timing, coordination, intent, and the broader operational situation. This shift becomes particularly evident during the debriefing phase. Learners demonstrate an increased ability to articulate the relationship between their decisions and their effects. Rather than evaluating decisions solely in terms of correctness, they begin to assess their appropriateness within the given context. A representative example of this discrepancy is summarized in Table 2.

Table 2. Example of discrepancy between technical correctness and operational effectiveness

| Aspect | Participant decision | Historical reference | Outcome |
|---|---|---|---|
| **Fire solution** | Technically correct firing data | Delayed engagement required | Target not effectively engaged |
| **Timing** | Immediate execution | Coordination required | Reduced operational impact |

From a behavioral perspective, the data indicate that decision-making under constrained conditions introduces variability in response patterns. Decision delays are not evenly distributed across the decision cycle. Instead, they tend to concentrate in phases associated with interpretation and situational assessment. This suggests that uncertainty and incomplete information have a stronger influence on performance than purely technical complexity. Communication behavior provides an additional layer of insight. Periods characterized by hesitation, fragmented verbalization, or increased response latency frequently coincide with phases of higher uncertainty.

Quantitatively, verbal response rates ranged from 82 to 145 words per minute, with fluctuations corresponding to moments of increased cognitive demand. While these observations remain exploratory, they support the assumption that communication patterns can serve as a supplementary indicator of decision-making processes. The integration of AI-supported analysis enables the aggregation and interpretation of these behavioral patterns. In the current implementation, the analysis is limited to basic metrics such as timing and interaction sequences.

Nevertheless, it demonstrates the feasibility of using automated tools to support evaluation in complex training environments. This represents a methodological advantage over traditional instructional approaches, where such data are typically unavailable or difficult to capture. No formal control group or experimental comparison was implemented at this stage. However, qualitative observations from debriefing sessions suggest a shift in learner reasoning. Participants increasingly evaluated decisions in terms of appropriateness within the operational context rather than procedural correctness alone.

Overall, the results suggest that VR-based instruction supports a more context-oriented understanding of artillery employment. By exposing learners to operational constraints and requiring active decision-making, the approach promotes analytical reasoning that extends beyond procedural knowledge [26].

## 6. Design and Preliminary Evaluation of VR-Based Artillery Scenarios

The results of the preliminary evaluation indicate that VR-based instruction addresses a critical gap in current artillery training: the disconnect between technically correct fire procedures and their operational application within constrained environments [1,2]. Traditional instructional approaches, particularly those focused on procedural drills and ballistic calculations, tend to isolate technical competence from the conditions under which artillery is actually employed. From a military training perspective, this represents a structural deficiency. Artillery effectiveness is not determined solely by the accuracy of fire solutions, but by the ability to integrate fires within a broader command and control (C2) framework [10,20], under conditions of uncertainty, time pressure, and incomplete information. The findings suggest that VR-based scenarios provide a viable means of exposing learners to these conditions in a controlled yet operationally relevant manner. The observed shift in learner behavior—from procedural execution toward context-driven decision-making—has direct implications for artillery training. Participants begin to recognize that fire missions are not isolated technical tasks, but components of a larger operational system involving coordination, prioritization, and intent. This aligns with the requirements of modern fire support, where effectiveness depends on synchronization across units, timing relative to maneuver, and the ability to operate within degraded communication environments. In this context, VR can be understood as a tool for training decision-making under conditions that are difficult to replicate using conventional methods. Live exercises provide realism but are resource-intensive and limited in repeatability. Simulation-based training, while scalable, often lacks the experiential dimension necessary for developing intuitive understanding of constraints [6,17]. VR occupies a middle ground, enabling repeated exposure to complex scenarios while preserving a high degree of situational immersion. The implications for command and control training are particularly significant. The scenarios demonstrate that delays in communication, ambiguity in information flow, and doctrinal constraints have a direct impact on the tempo and effectiveness of fire support. Training that does not explicitly incorporate these factors risks producing operators who are technically proficient but operationally ineffective. VR-based environments allow these variables to be systematically introduced and manipulated, creating conditions in which learners must adapt their decision-making processes accordingly.

At the same time, the integration of AI introduces new possibilities for evaluating performance in artillery training. Behavioral data, including decision timing, sequencing of actions, and communication patterns, provide a basis for assessing not only what decisions were made, but how they were made. This represents a shift from outcome-based evaluation toward process-oriented assessment, which is more aligned with the realities of command decision-making [18]. However, these advantages must be considered alongside significant limitations. The effectiveness of VR-based training is highly dependent on the fidelity of the scenarios. Inaccurate representation of terrain, communication structures, or doctrinal constraints may lead to incorrect mental models, which can be more harmful than incomplete knowledge. In a military context, this is a non-trivial risk. Furthermore, VR cannot replace live training or real-world exercises. Physical constraints, stress factors, and the complexity of real operational environments cannot be fully replicated in a virtual setting. The role of VR should therefore be understood as complementary, providing a bridge between theoretical instruction and field training rather than a substitute for either. Another critical limitation concerns the risk of technological overreliance. The introduction of advanced tools such as VR and AI does not automatically translate into improved training outcomes. Without clearly defined objectives, structured scenarios, and instructor-led guidance, the use of such technologies may result in superficial engagement rather than meaningful learning. Finally, the question of evaluation remains unresolved. While the proposed indicators—such as decision latency, adaptability, and coherence—offer a promising direction, they require further validation to ensure reliability and relevance in operational contexts. Establishing standardized evaluation frameworks for decision-making in artillery training remains an open challenge.

In summary, the findings suggest that VR-based instruction has the potential to significantly enhance artillery training by reintroducing context, constraints, and decision-making into the learning process. Its primary contribution lies in bridging the gap between technical proficiency and operational effectiveness. However, its successful implementation depends on methodological rigor, scenario fidelity, and its integration within a broader training system that includes both theoretical and practical components.

## 7. Conclusions

The findings of this study indicate that traditional approaches to teaching artillery history are insufficient for developing an operational understanding of artillery employment. The core limitation lies in the separation of technical knowledge from the conditions under which it is applied. As a result, learners may achieve procedural correctness without understanding its operational relevance. The integration of Virtual Reality into instruction addresses this limitation by embedding learning within historically and operationally grounded contexts. VR-based scenarios expose learners to key constraints that shape real-world decision-making, including uncertainty, limited observation, communication delays, and doctrinal restrictions. This shifts the focus from technical execution toward context-dependent reasoning, which is essential for effective artillery employment.

A central contribution of the study is the demonstration that decision-making under constraints can be systematically represented and analyzed within an educational framework. By combining immersive scenarios with behavioral and communication-based indicators, the proposed approach enables evaluation of how decisions are made, not only whether they are correct. From a training perspective, VR can be understood as a bridging tool between theoretical instruction and live exercises. It enables repeated exposure to complex decision-making situations that are difficult to reproduce in conventional training environments. This is particularly relevant for command and control processes, where timing, coordination, and intent play a decisive role. At the same time, the results highlight that technical correctness should not be treated as a sufficient proxy for operational effectiveness. Effective artillery employment depends on the integration of technical solutions within a broader decision-making context. This has direct implications for how artillery training is structured and evaluated.

The study also demonstrates the potential of integrating Artificial Intelligence as a supporting component for evaluation and feedback. AI-assisted analysis enables the processing of behavioral data and supports structured reflection. However, its role remains auxiliary and dependent on clearly defined methodological frameworks. Several limitations must be acknowledged. The current results are exploratory and based on a limited set of scenarios and participants. The validity of proposed indicators, such as decision latency and speech-based metrics, requires further verification. In addition, the effectiveness of the approach depends on scenario fidelity and instructional design quality. For military practice, the implications are clear. Training approaches that focus predominantly on procedural accuracy risk neglecting the decision-making processes that determine operational effectiveness. VR-based instruction provides a viable means of addressing this gap, but only when integrated into a broader training system that combines theoretical instruction, simulation, and live experience. Future research should focus on expanding empirical data, validating evaluation metrics, and testing the approach across different operational contexts. Establishing robust and transferable methods for assessing decision-making quality remains a key step for the wider adoption of VR-supported training in artillery and related domains.

**Acknowledgements.** The authors would like to express their sincere gratitude to the company YORD for their generous support, including the provision of equipment, as well as for their valuable cooperation throughout the project.

**Funding sources.** This work was supported by Czech Ministry of Defence from project LANDOPS (grant number DZRO-FVL22-LANDOPS) and by Czech Ministry of Education, Youth and Sports from project System Modernization of the CzechArmed Forces Artillery Training using Simulation Technologies (grant number SV25-FVL-K107-KOR).

**References**

1. **Blaha M., Potuzak L., Sustr M., Ivan J., Havlik T.** Simplification Options for More Efficient Using of Angular and Linear Measuring Rules for Fire Control. Int. J. Educ. Inf. Technol., 2021, 15, p. 28–34.
2. **Drabek J., Sustr M., Potuzak L., et al.** Contingency and Emergency Manual Procedures for Calculation Firing Data Using Direction and Distance Coefficients. Engineering Reports, 2025, 7, e70252.
3. **Varecha J., Majchút I.** Modelling of Artillery Fire and Simulation of its Efficiency. In: Proceedings of the International Conference Knowledge-Based Organization, 2019, 25, p. 174–180.
4. **Zahradnicek P., Botik M., Rak L., Hrdinka J.** Modern Battlefield and Necessary Reflection in Military Leader's Education and Training. Vojenské rozhledy, 2023, 32, p. 110–122.
5. **Pekar O., Novák J., Varecha J., et al.** Bridging Theory and Practice in Military Education Through Advanced Technologies. In: ECGBL Proceedings, 2024, 18, p. 1056–1060.
6. **Gouveia H., Borges J.** The Impact of Numerical Shifts on the Field Artillery Firing Accuracy. In: Developments and Advances in Defense and Security. Springer, 2024, p. 135–145.
7. **Hujer V., Slouf V., Farlik J.** Utility as a Key Criterion in Decision-Making on Structure of Ground-Based Air Defence. In: Modelling and Simulation for Autonomous Systems. Springer, 2022, p. 249–260.
8. **Endsley M.R.** Toward a Theory of Situation Awareness in Dynamic Systems. Human Factors, 1995, 37 (1), p. 32–64.
9. **Klein G.** Sources of Power: How People Make Decisions. MIT Press, 1998.
10. **Hutchins E**. Cognition in the Wild. MIT Press, 1995.
11. **Kolb D.A**. Experiential Learning: Experience as the Source of Learning and Development. Prentice Hall, 1984.
12. **Makransky G., Petersen G.B**. Immersive Virtual Reality and Learning: A Meta-Analysis. Educational Psychology Review, 2021, 33, p. 937–959.
13. **Radianti J., Majchrzak T.A., Fromm J., Wohlgenannt I.** A Systematic Review of Immersive Virtual Reality Applications for Higher Education. Education and Information Technologies, 2020, 25, p. 4691–4730.
14. **Slater M., Sanchez-Vives M.V.** Enhancing Our Lives with Immersive Virtual Reality. Frontiers in Robotics and AI, 2016, 3, p. 74.
15. **Jerald J.** The VR Book: Human-Centered Design for Virtual Reality. Morgan & Claypool, 2015.
16. **Dede C.** Immersive Interfaces for Engagement and Learning. Science, 2009, 323 (5910), p. 66–69.
17. **Graesser A.C., McNamara D.S.** Computational Analyses of Multilevel Discourse Comprehension. Topics in Cognitive Science, 2011, 3 (2), p. 371–398.
18. **Litman D.J., Forbes-Riley K.** Speech-Based Affective Computing for Educational Systems. In: The Oxford Handbook of Affective Computing, 2015.
19. **Sarter N.B., Woods D.D.** Situation Awareness: A Critical but Ill-Defined Phenomenon. International Journal of Aviation Psychology, 1991, 1 (1), p. 45–57.
20. **Sustr M., Potuzak L., Blaha M., Ivan J.** Multiple Round Simultaneous Impact Fires and Possibilities of Its Application in Czech Army. Vojenské rozhledy, 2020.
21. **Blaha M., Sobarna M.** Some Development Aspects of Perspective Fire Support Control System in Czech Army Conditions. In: Proceedings of the 6th WSEAS International Conference on Dynamical Systems and Control. Sousse, 2010, p. 179–183.
22. **Němec P., Stodola P., Pecina M., et al.** Optimization of the Weighted Multi-Facility Location Problem Using MS Excel. Algorithms, 2021, 14, 191.
23. **Odehnal J., Neubauer J., Olejnicek A., et al**. Empirical Analysis of Military Expenditures in NATO Nations. Economies, 2021, 9, 107.
24. **Świętochowski N., Varecha J., Korec D., Vitoul V., Hercik M.** Immersive Training of Artillery Observers with Integrated Artificial Intelligence, 2025.
25. **Rolenec O., Bilina M., Pekar O., Drozd J., Gottvaldova N.** Unmanned Aerial Vehicle LiDAR Scanning for Railway Security: Pre- and Post-Explosion Analysis. In: 2025 International Conference on Military Technologies (ICMT). IEEE, 2025, p. 1–7. https://doi.org/10.1109/icmt65201.2025.11060900
26. **Ivan J., Sustr M., Gregor J., Potuzak L., Varecha J.** Advancing Soil Sampling Techniques for Environmental Assessment of Artillery Impact Zones. Journal of Ecological Engineering, 2025, 26 (5), p. 1–14. https://doi.org/10.12911/22998993/196688
27. **Korec D., Blaha M., Barta J., Varecha J.** Innovative Approaches to the Use of Artillery in Wildfire Suppression. Fire, 2025, 8 (6), p. 232. https://doi.org/10.3390/fire8060232

28. **Sustr M., Vajda M., Blaha M., Ivan J., Korec D.** Artillery Officer Education and the Interoperability Challenge in Joint Fires: A Czech–Slovak Comparison. Cogent Education, 2025, 12 (1). https://doi.org/10.1080/2331186x.2025.2533308
29. **Blaha M., Varecha J., Drabek J., Novak J.** Comparison of AI Speech-to-Text Systems and Their Application in Artillery Command and Fire Control Systems. In: Communications in Computer and Information Science. Cham: Springer Nature Switzerland, 2025, p. 82–95. https://doi.org/10.1007/978-3-032-04339-9_6
30. **Havlik T., Sustr M., Ivan J., Pekar O., Musinka M.** Evaluation of the Effectiveness of a Firing Battery in Self-Defense and Protection in the Area of Firing Positions Using Constructive Simulation. The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology, 2024. https://doi.org/10.1177/15485129241291579
31. **Klima M., Bures M., Blaha M.** Ant Colony Optimization Based Algorithm for Test Path Generation Problem with Negative Constraints. In: 2024 IEEE 24th International Conference on Software Quality, Reliability and Security (QRS). IEEE, 2024, p. 701–712. https://doi.org/10.1109/qrs62785.2024.00075
32. **Neubauer J., Vlkovsky M., Michalek J.** Statistical Modeling of Cargo Securing on Selected Military Trucks and Road Surfaces. The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology, 2024, 21 (3), p. 341–355. https://doi.org/10.1177/15485129241227012
33. **Gouveia H., Freitas R**. Innovations and Trends in Field Artillery Weapon Systems. Cogent Social Sciences, 2024, 10 (1). https://doi.org/10.1080/23311886.2024.2411867
34. **Slouf V., Blaha M., Pekar O., Brizgalova L., Mullner V.** An Alternative Model for Determining the Rational Amount of Funds Allocated to Defence of the CR. Obrana a strategie, 2023, 23 (1), p. 149–172. https://doi.org/10.3849/1802-7199.23.2023.01.149-172
35. **Ivan J., Sustr M., Sladek D., Varecha J., Gregor J.** Emergency Meteorological Data Preparation for Artillery Operations. In: Proceedings of the 20th International Conference on Informatics in Control, Automation and Robotics. SCITEPRESS, 2023, p. 250–257. https://doi.org/10.5220/0012205500003543
36. **Hasilova K., Valis D.** Reliability Estimation of Critical Infrastructure Segment Backed up by the Circular Data Analysis. In: 2023 International Conference on Military Technologies (ICMT). IEEE, 2023, p. 1–7. https://doi.org/10.1109/icmt58149.2023.10171311
37. **Kratky M., Pekar O., Ivan J.** Simulation Support of Teaching and Research Activities at the Departments of Combat Support Forces at the University of Defence. In: 2023 International Conference on Military Technologies (ICMT). IEEE, 2023, p. 1–8. https://doi.org/10.1109/icmt58149.2023.10171204
38. **Ivan J., Sustr M., Pekar O., Potuzak L.** Prospects for the Use of Unmanned Ground Vehicles in Artillery Survey. In: Proceedings of the 19th International Conference on Informatics in Control, Automation and Robotics. SCITEPRESS, 2022, p. 467–475. https://doi.org/10.5220/0011300100003271
39. **Casar J., Kratky M.** Modelling and Simulation of Ground Based Air Defence War Games. In: 2022 20th International Conference on Mechatronics – Mechatronika (ME). IEEE, 2022, p. 1–6. https://doi.org/10.1109/me54704.2022.9983183
40. **Hujer V., Slouf V., Farlik J**. Utility as a Key Criterion of a Decision-Making on Structure of the Ground Based Air Defence. In: Lecture Notes in Computer Science. Cham: Springer International Publishing, 2022, p. 249–260. https://doi.org/10.1007/978-3-030-98260-7_15
41. **Nemec P., Stodola P., Pecina M., Neubauer J., Blaha M**. Optimization of the Weighted Multi-Facility Location Problem Using MS Excel. Algorithms, 2021, 14 (7), p. 191. https://doi.org/10.3390/a14070191
42. **Drozd J., Rak L., Zahradnicek P., Stodola P., Hodicky J.** Effectiveness Evaluation of Aerial Reconnaissance in Battalion Force Protection Operation Using the Constructive Simulation. The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology, 2021, 20 (2), p. 181–196. https://doi.org/10.1177/15485129211040373
43. **Racek F., Balaz T., Krejci J.** Evaluation of Target Acquisition Performance in Photosimulation Test. In: Target and Background Signatures V. SPIE, 2019, p. 24. https://doi.org/10.1117/12.2532807
44. **Farlik J., Kratky M., Casar J., Stary V.** Multispectral Detection of Commercial Unmanned Aerial Vehicles. Sensors, 2019, 19 (7), p. 1517. https://doi.org/10.3390/s19071517
45. **Cimr D., Tomaskova H., Cimler R., Kuhnova J., Slouf V.** A System to Evaluate an Air-Strike Threat Level Using Fuzzy Methods. In: Lecture Notes in Computer Science. Cham: Springer International Publishing, 2018, p. 322–331. https://doi.org/10.1007/978-3-319-98446-9_30
46. **Blaha M., Brabcova K.** Decision-Making by Effective C2I System. In: Proceedings of the 7th International Conference on Information Warfare & Security. Seattle: Academic Publishing Limited, 2012, p. 44–50.
47. **Blaha M., Brabcova K.** Communication Environment in the Perspective Automated Artillery Fire Support Control System. In: Proceedings of the 10th WSEAS International Conference on Applied Informatics and Communications (AIC '10). Taipei: WSEAS Press, 2010, p. 236–239.
48. **Blaha M., Sobarna M.** Some Development Aspects of Perspective Fire Support Control System in Czech Army Conditions. In: Proceedings of the 6th WSEAS International Conference on Dynamical Systems & Control (CONTROL 2010). Tunisia: WSEAS Press, 2010, p. 179–183.