7.2 Optimizing Decision Preparedness by Adapting Scenario Complexity and Automating Scenario Generation

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Abstract. Klein's recognition-primed decision (RPD) framework proposes that experts make decisions by recognizing similarities between current decision situations and previous decision experiences. Unfortunately, military personnel are often presented with situations that they have not experienced before. Scenario-based training (SBT) can help mitigate this gap. However, SBT remains a challenging and inefficient training approach. To address these limitations, the authors present an innovative formulation of scenario complexity that contributes to the larger research goal of developing an automated scenario generation system. This system will enable trainees to effectively advance through a variety of increasingly complex decision situations and experiences. By adapting scenario complexities and automating generation, trainees will be provided with a greater variety of appropriately calibrated training events, thus broadening their repositories of experience. Preliminary results from empirical testing (*N*=24) of the proof-of-concept formula are presented, and future avenues of scenario complexity research are also discussed.

1.0 INTRODUCTION

Decision-making in the military has evolved significantly since the eras of the phalanx and the Napoleonic regiment. Their strict, hierarchical command and control is inappropriate for the asymmetrical conflicts warfighters face now. Modern warfighters, often acting in small, distributed teams, are expected to make numerous, rapid decisions based on ambiguous information, all the while avoiding conflicts with rules of engagement, missions orders, and commander's intent. Unfortunately, lacking personal experience to draw upon, junior military personnel are often ill-prepared to make such complex decisions, and the outcomes of poor decisions may be disastrous: incorrect actions engaged, unnecessary risks taken, missions jeopardized, or casualties received.

Military personnel faced with unfamiliar situations are at a dangerous disadvantage if they lack the necessary decision-making skills. Unique situations are inherently risky and dangerous, fertile ground for poor decision-making [1]. Such situations demand increased attention, while draining vital cognitive resources [2], and they may engender anxiety that can detrimentally influence decision-making [3]. However, the more familiar a situation, the less risk and danger involved, and the better the decision-making. According to Klein's recognition primed decision (RPD) framework, decisions are made based upon decision-makers' available "pool" of internalized previously experienced situations [4]. Simply, the more experiences and situations individuals can draw from, the more likely they are to successfully navigate through multiple decision points. In regards to simulation, however, more experiences do not necessarily translate to a perception of scenario fidelity. Multiple experiences within simulation that are misaligned to the trainee's level of experience may not be perceived as accurately reflecting the complexity to be found in actuality. In their experiments, Bradley and Shapiro [5] found that at extreme levels of complexity, when cognitive capacity was taxed, everything became more real to participants. The challenge for simulation then, is presenting the optimum level of complexity to engender a sense of fidelity.

Just as decision-making in the military has evolved, so have its methods of training. Today, scenario-based training (SBT), defined as the purposeful instantiation of simulated events to create desired psychological states [6], is a widely accepted instructional approach. One of the strengths of SBT is the presentation of varied situations that allow trainees to experience real-world problems prior to engagement. Systematically presenting training along a trajectory similar to Bloom's revised taxonomy [7], proceeding from declarative knowledge to higher-order levels of abstraction and creation, grounds the content and delivery in well-documented learning theory. Through such training, personnel can efficiently and effectively learn to integrate multiple skills, cope with realistic distracters, practice their higher order cognitive skills, and exercise naturalistic decision-making [8].

1.1 SBT Technologies

Although SBT can be delivered in a variety of ways, the remainder of this paper refers to scenario-based military training delivered through computer-generated virtual environments.

Currently, in the practice of SBT, scenarios are chosen for implementation by a trainer based on training objectives, a description of the scenario, the trainees' level of experience, and timeline requirements. Although training manuals may present sequences of training, they typically lack explicit recommendations for the content or sequencing of training scenarios. Thus, without a clear progression of scenarios, trainers rely on their own judgment when determining the scenarios' tasks and the order of presentation of scenarios within a set. Consequently, a trainer's sequencing may not align with trainees' levels of experience or performance, and mismatching trainees with training events can result in diminished—or even negative—decision preparedness.

Recent efforts to develop a SBT system that adapts to trainees' levels of experience have been undertaken by the authors, who are attempting to create *automated* methods that more effectively advance trainees through a variety of increasingly complex training scenarios.

To achieve this goal, the investigators needed to operationalize the notion of *scenario complexity*. That is, the authors needed to objectively define the subjective idea of scenario difficulty. This objective formulation is necessary in order to develop the software algorithms that perform the automated instructional adaptation.

In the following section the authors present a brief definition of scenario complexity, identify and describe each of the characteristics used in the calculation of scenario complexity, and discuss the role of scenario complexity in the automation of scenario generation.

2.0 SCENARIO COMPLEXITY

To ensure trainees receive scenarios appropriate to their experience level, it is crucial to objectively define and instantiate *scenario complexity* so that computer-based training software can automatically assemble appropriate SBT sequences. Successful instantiation depends on taking the subjective and abstract and making it objective and concrete; that is, creating an *objective* computational metric of the *subjective* notion of difficulty.

The authors define *scenario complexity* as the objective quality of a scenario, which interacts with individual characteristics (such as trainees' expertise) to yield an individual's perception of the scenario's difficulty [9]. Most importantly, scenario complexity is calculated based upon three scenario elements that are *extrinsic from* rather than *intrinsic to* trainees: task complexity, task framework and cognitive context moderators. To be clear, the authors purposefully refrain from attempting to incorporate individual perceptions. Subjective interpretation of a task's difficulty or an individual's affective state in relation to a particular characteristic is un-actionable and cannot be calculated. It is for the purpose of operationalizing and incorporation into program software that objective calculation is pursued. For detailed description of the formula see Dunne et al. [10].

2.1 Scenario Complexity Characteristics

The authors' computational definition of scenario complexity is as follows:

$$SC = (TC + TF) * CCM \qquad \text{Eq. (1)}$$

where SC = scenario complexity, TC = Task complexity, TF = Task framework, and CCM = Cognitive context moderators.

Each of the variables that comprise the total SC can be manipulated to increase or decrease the total SC. In addition, they can be altered to maintain the trainee in the same complexity range while at the same time presenting variety within the scenario. Each variable is calculated through individual functions that involve the following sub-variables.

2.1 Task Complexity

The task complexity component is subdivided into component complexity and coordinative complexity.

2.1.1 Component Complexity

The component complexity characteristic is composed of three sub- variables: the number of subtasks, required acts, and information cues.

First, component complexity considers the number of subtasks. Each training scenario is designed around at least one task with attendant learning objective(s). A task may stand alone, without a sub-task, but frequently, tasks include sub-tasks that must also be performed.

Second, each subtask requires one or more specific acts. Although a required act is principally a pattern of behavior, novice trainees internalize the conscious choice to engage in the behavior until it becomes automatic. Increasing the number of required acts presents greater opportunity for transitioning conscious behavior to unconscious, automatized decisions.

Finally, each subtask may require monitoring of information cues. An information cue is a discrete source of information that must be monitored and/or processed from the environment. The trainee who is aware of these cues and chooses to monitor them will attain the desired performance more efficiently than a trainee who does not.

2.1.2 Coordinative Complexity

Coordinate complexity is concerned with the integration of subtasks and associated acts, which may be necessary for successful task completion. These subtasks are integrated and involve synchronization of activities to achieve the common goal or objective [11].

Without coordination of these subtasks and acts, trainee performance will suffer. By manipulating the degree of integration, trainees are presented with increasing levels of scenario complexity requiring, in turn, a greater number of decision points.

2.2 Task Framework

Task framework accounts for the relation between task paths and the outcome associated with each, and it addresses which outcomes are possible in a given task [12].

The authors suggest it is the task framework characteristic where the interplay of decision preparedness, performance and complexity is most acute. Tasks such as those with a single goal and a single means or path to achieve that goal, are well-defined. Tasks with multiple goals with several possible means or paths to achieve the goals are ill-defined tasks. Deciding if a particular means or path will achieve the desired goal requires a resolution of existing ambiguity; a calculation of potentiality for each path's success. Ambiguity and complexity make it difficult for decision-makers to determine what the possible outcomes might be, let alone the value they assign to them [13]. Increasing ambiguity and complexity is therefore conjectured to be highly influential in advancing decision preparedness.

2.3 Cognitive Context Moderators

Cognitive context moderators address factors that often increase stress and distraction present in the scenario and are defined as external stimuli that affect the operator by increasing load and reducing cognitive resources for the task, thus causing less complex decisions to appear more complex.

These moderators can influence the resolution or quality of the evidence available for supporting judgments. According to Macmillan and Creelman [14] when attempting a forced-choice judgment to identify, for example "known or unknown", performance will be superior during a clear daylight encounter compared to night or under hazy conditions because the available evidence is superior.

It must be reiterated that these characteristics are built into the scenario; it remains the decision of the trainee to engage in these acts, monitor cues and satisfy scenario criteria. Through presentation of increasing levels of complexity, the scenarios contribute to the growing pool of experiences from which the trainee will draw.

The authors suggest automated generation of scenarios that take trainees on an efficient and effective trajectory towards optimized decision preparedness can be accomplished by this operationalization of scenario complexity. To ensure that adaptive generation results in positive outcomes, systematic implementation of this training framework must be grounded in decision-making and learning theory.

The following section describes two major theories adaptive scenario generation draws upon to increase decision preparedness.

3.0 OPTIMIZING DECISION PREPAREDNESS

The ability to make timely, appropriate, and effective decisions is an essential competence for warfighters [15]. Buch and Diehl [15] found that increases in the quality of decision-making have largely been by-products of in-field experience. However, they concluded that judgment and decision-making capability can be improved through training, incorporating situation-specific exercises and increasing the variety of variables as training progressed.

With an objective value for each scenario's complexity, variables can be manipulated to increase or decrease variety and complexity. This manipulation must be calibrated to trainee performance, aligning the level of complexity associated with a scenario to the instructional needs of trainees. However, in order to align the scenario to an individual's training needs—making the scenario that is "just right" —the simulation must employ a systematic instructional methodology [16].

The following section describes how the instructional methodology, based on Bloom's taxonomy, is supported through the operationalization of scenario complexity for SBT. Also discussed is the role of automated scenario generation and how it is utilizes Klein's recognition-primed decision-making framework and, by extension, Klein and Baxter's cognitive transformation theory [17] to improve decision preparedness. The section also describes the well-documented instructional efficacy of Vygotsky's zone of proximal development [16], used to enable proper alignment and sequencing of scenarios.

3.1 Recognition-primed Decision-making (RPD)

Recent decision-making theories have focused on decisions that are made in complex situations with high stakes, uncertainty and time pressure [13]. Naturalistic decision-making theory (NDM) attempts to explain such decisions by suggesting that a decision-maker continually assesses a situation in order to recognize familiar characteristics and make judgments [19]. NDM has been observed across domains, such as firefighting and the military [20], where the decision-maker initially assesses the situation, looks for familiar patterns or prototypes, determines which goals make sense, identifies the relevant cues to expect, and determines what action should will be most appropriate.

Under the umbrella of NDM research, the RPD model has gained significant influence over the past 10 to 15 years. This model is based on the supposition that, in complex situations, humans usually make decisions based on the recognition of similarities between the current decision situation and previous decision experiences. Simply, Klein proposes that decisions are made based on the recall of the consequences of previous decisions made in similar situations.

Cognitive studies have shown that over 95% of human decisions conform to the RPD model in time-stressed situations [21]—the very type of situation frequently encountered by military personnel.

An extension of RPD is cognitive transformation theory [CTA]. This theory states that as novices progress towards expertise they develop "knowledge shields" that serve to protect their established concepts. These shields can negatively affect knowledge and skills acquisition and, in the operational theater, may lead to situations where default decisions are made based on biased judgment rather than experience [17].

However, Klein and Baxter reference Waller, Hunt, and Knapp [22] who found that varied and sufficient exposure to virtual training environments provides trainees with the needed practice to construct valid mental models and alleviate the obstacles created by such knowledge shields [17].

3.2 Zone of Proximal Development (ZPD)

The theory of the zone of proximal development (ZPD) is the scientific basis for why training (in this case, scenario) difficulty must be appropriately matched to trainees' current skill levels. The ZPD is the range within which learning and training tasks are neither too hard nor too easy. According to Vygotsky, development will only occur when a trainee is confronted by a task that lies within the zone, because if a task is too easy then no development will happen (although gains in fluency and accuracy may occur simply through repetition) [23] and if a task is too difficult to complete successfully, no cognitive development will occur [24] and motivation may suffer.

3.3 Implementation

For illustrative purposes let us say during SBT, a trainee performs exceptionally well. They have attained the goals and successfully navigated decision points. Another trainee has not performed so well. They have not attained the goals, and their decisions were inadequate. Following the principle of ZPD the next scenario in sequence should be neither too difficult nor too easy. Due to such differing performance, under today's SBT approach, it cannot be expected that one scenario will address the learning needs of both trainees. However, if the next scenario in sequence could increase in complexity for the high performer while either maintaining the current complexity level, with variation, or remediating at a lower complexity range for the other trainee, then the training should be more effective and efficient. Achieving this is the authors' goal.

Scenario complexity ranges derived from the computational formula developed by the authors, allow software to determine, with or without manual input from the trainer, the appropriate sequence of experiences for both of these trainees. If, according to ZPD, negative training exists outside both the upper and lower bounds, then scenario complexity defines the upper and lower ranges of the complexity of the appropriate sequenced scenario.

Aligning scenario sequencing to trainee performance, therefore, ensures that trainees are not presented with decision points and situations which are too hard or too easy, but remain in the area of ideal learning, while presenting varied situations and experiences increasing decision preparedness.

To establish empirical basis for this theory of scenario complexity an initial study is being conducted. The focus of this study, as well as its design, methodology, and preliminary findings are presented in the following section.

4.0 EXPERIMENTATION

A pilot study was conducted to ascertain if the researchers' theory, equations, and hypotheses are usable and conceptually sound. Incorporating lessons learned from this pilot study, any reformulation to the original equation that is suggested by the results will precede further research. The end-state study will include construction of dynamic scenario-based training of varying levels of complexity designed by military personnel.

4.1 Design and Methodology

This pilot study involved a single sample group (*N*=24) comprised of undergraduate students recruited from a large southeastern university. Each participant completed four surveys, which asked participants to indicate their perception of the complexity levels of various situations. These situations' complexity levels were calculated *a priori* by the authors, using the described scenario complexity formula.

The first series of 6 questions asked the participants to indicate on a scale of 1-20 how simple or complex they thought it would be to drive a car: (Q_1) in an empty parking lot, (Q_2) to a familiar destination in light traffic, (Q_3) to an unfamiliar destination in a familiar city, (Q_4) to an unfamiliar destination in an unfamiliar city using a map, (Q_5) to a familiar destination in heavy traffic and severe thunderstorm, and (Q_6) to an unfamiliar destination using a map, in light traffic and mild rain.

The second series of 6 questions asked the participants to indicate how simple or complex they thought it would be to: juggle three balls of different sizes (Q_7), juggle two balls and walk at the same time (Q_8), juggle two balls (Q_9), juggle three balls of the same size and walk (Q_{10}), juggle three balls of the same size while reciting the ABC's (Q_{11}), and juggle two balls of different sizes and walk while reciting the ABC's (Q_{12}).

The third series of 6 questions asked the participants to indicate how simple or complex they thought it would be to drive a car: in an empty parking lot while talking on the phone (Q_{13}), to a familiar destination in light traffic while talking on the phone (Q_{14}), to an unfamiliar destination while talking on the phone (Q_{15}), to an unfamiliar destination with a map while talking on the phone (Q_{16}), to a familiar destination in heavy traffic and severe thunderstorm while talking on the phone (Q_{17}) and, to an unfamiliar destination with a map in light traffic and mild raid while talking on the phone (Q_{18}).

The fourth series of questions set the participants into a single scenario comprised of 7 different situations and were asked to indicate how simple or complex they thought each situation would be to: drive to their friends house (Q_{19}), drive to their friends new house where they've never been before (Q_{20}), surf (Q_{21}), play a ping-pong toss game (Q_{22}), play the toss game with a fan aimed out over the game (Q_{23}), choose from a large menu of pizza toppings under a time constraint (Q_{24}) and to pick one of two sodas (Q_{25}).

4.2 Hypotheses

The authors hypothesized that the scenario complexity computation calculated by the authors would be similar to the results identified by the participants. In other words, the authors expected that the formula would yield relatively comparable results, regardless of who assessed the described scenarios.

4.3 Results

An independent one-sample *t*-test was conducted on the participant (*n*=24) responses to evaluate whether their means were significantly different from the test values established *a priori*.

Z-scores were also derived to ascertain the degrees of agreement among participants' values. *Z*-scores between -1.249 and 1.249 indicate relative agreement as to a situation's difficulty. *Z*-scores < -1.25 or > 1.25 represent significant disagreement.

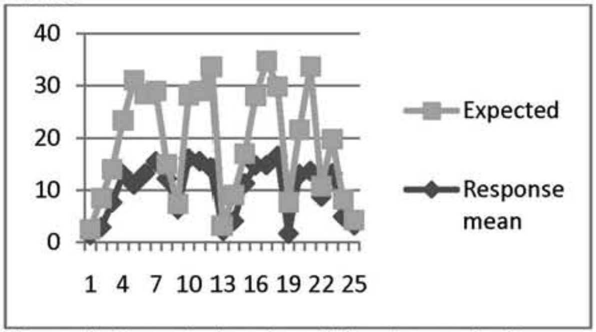
The following table shows the z-scores for each item. The total mean and standard deviation are noted below.

Calculated Z-scores*

Item #	Response Mean	*A Priori* Expected Score	*t-test value (mean/expected)*	*Participants'* Z-Scores
1	1.45	1	*p* = .06	-1.75
2	2.91	5.6	*p* = .00	-1.46
3	7.62	6.4	*p* = .08	-.54
4	13	10.4	*p* = .00	.52
5	11.08	20	*p* = .00	.14
6	13.2	15.2	*p* = .03	.56
7	15.5	13.5	*p* = .06	1.01
8	12.2	2.8	*p* = .00	.36
9	6.37	1	*p* = .00	.78
10	16.08	12.1	*p* = .00	1.13
11	15.54	13.5	*p* = .00	1.02
12	14.33	19.3	*p* = .04	.78
13	2.2	1	*p* = .00	-1.6
14	4.12	5	*p* = .00	-1.22
15	11.29	5.7	*p* = .05	.19
16	14.75	13.3	*p* = .00	.87
17	14.79	20	*p* = .1	.87
18	16.58	13.3	*p* = .00	1.22
19	1.7	6	*p* = .00	-1.69
20	13	8.6	*p* = .00	.52
21	13.66	20	*p* = .00	.65
22	8.79	2	*p* = .00	-.31
23	13.2	6.6	*p* = .00	.56
24	4.95	3.3	*p* = .11	-1.06
25	3.29	1	*p* = .00	-1.39

Table 1: Calculated Z-scores, means, and *t*-test results; **N* = 24, 95% confidence.

In the graph below the *a priori* complexity levels and participants' responses are illustrated. The light line represents the calculated levels while the dark line represents the mean levels of the aggregated participant responses.



Expected levels and participant response means

Figure 1: Expected and participant complexity levels

4.4 Conclusion

Two salient conclusions can be drawn from the results of this study. First, *Z*-scores indicate significant disagreement at both ends of the complexity spectrum, suggesting that the low- and high-end complexity scenarios have a wider range of responses than do the middle-ground values. Second, there was a significant level of agreement of perceived complexity relating to those situations which occupy the middle-ground.

5.0 DISCUSSION

These results indicate areas of both promise and challenge. As a proof of concept, the authors believe their formalization of scenario complexity is headed in the correct direction; however, there are adjustments and considerations which must be accounted for in future iterations. Attempting to quantify subjective perceptions is rife with inconsistency. Two participants may give two different values for the same situation even though they both perceive the situation as being very simple. Further, levels of experience may have, as Klein suggests, played a discriminating role. Participants with a larger repository of experiences to draw from may have perceived the described situations with a lower level of difficulty compared to those with fewer experiences. This argues not only for the support of RPD but also for the necessity to adapt training and complexity levels to the trainee within their zone of proximal development or risk de-motivation and inefficient training.

Additionally, disparity between participant responses and the *a priori* calculated values may point to participants' over-confidence and/or a lack of understanding of the characteristics of the situation. That is, while the scenario complexity formula takes into account such characteristics as number of task outcomes and cognitive context moderators, participants may not be able to readily identify such attributes. Similarly, participants may identify such factors, but may not consider them impactful. For instance, in the item that asked participants for an evaluation of their ability to utilize a cell-phone while in traffic during a thunder storm, over-confidence may lead some to inaccurately assess the challenge of performing under such conditions.

Lessons from this pilot study suggest further refinement of both the formulation of scenario complexity as proposed, and of the research design. In order to investigate validity and reliability across the entire spectrum of complexity, future research requires recalculation of the weight given to each characteristic, and reformulation of the task-framework equation in particular, in addition to controlling for levels of experience and including more detailed instructions for participants.

Branching outward from this avenue of investigation, promising areas of research include, but are certainly not limited to, investigating the role of cognitive load on scenario complexity. That is, does objective calculation of complexity adequately address both a novice and expert trainee's different requirements of cognitive load? Second, in respect to integration of team members, how do multiple agents impact an individual's performance in dynamic, adaptive scenarios? Third, to what degree is perception of scenario fidelity affected by increasing scenario complexity following Vygotsky's ZPD? Finally, what role do personal characteristics such as metacognition and self-efficacy play in trainees' performance?

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8.0 ACKNOWLEDGMENTS

This project is sponsored by the Next generation Expeditionary Warfare Intelligent Training (NEW-IT) (N00014-08-C-0186) contract from the Office of Naval Research.