The 7$^{\text{th}}$ Patient: Designing an Educational Game for High School AI and Probability Education

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Abstract. Probability is one of the most useful math skills in everyday life. Developing awareness of probability concepts and using them appropriately in problem-solving is of great importance to all students. Artificial Intelligence (AI) offers a setting for probability (and AI) problem-solving that is relevant and meaningful to students, as probability is one of three mathematical concepts (along with logic and computation) that are foundational to AI. One approach to bring AI to the K-12 classroom that has shown promise is digital game-based learning. In this paper, we discuss the design of an educational game, *The 7th Patient*, to illustrate probability concepts in AI algorithms and to provide an environment to support the reciprocal development of math and AI skills. The game integrates the Common Core State Standards for mathematics, particularly independent and conditional probability. The game's AI learning centers around the Bayesian networks: identifying variables, constructing the network with probability tables, performing inference, and decision-theoretic reasoning. We conducted an efficacy study and a cognitive-interview study with high-school students. This paper presents the game design and findings from these two studies.

Keywords: First keyword · Second keyword · Another keyword.

1 Introduction

Probability is one of the most useful math skills in everyday life. Developing awareness of probability concepts and using them appropriately in problem-solving is of great importance to all students. Some argue that no other math knowledge is more important to students than probability theories and statistics, given its instrumental role in disciplines beyond mathematics, including biology, medicine, economy, sports [21]. Developing awareness of probability concepts and using them appropriately in problem-solving is of great importance to all students [11]. Unfortunately, studies of secondary school students revealed that the percentage of students who understand the key concept of probability was much lower than suggested by the National Assessment of Educational Progress [26]. Many students' understandings of probability concepts were based on their preconceived meanings, and not aligned to established disciplinary meanings [23]. This leads to problems in decision-making later in life, where almost everyone, including professional statisticians, suffer from systematic biases in judgments of probability while maintaining strong misconceptions [50, 20].

Artificial Intelligence (AI) offers a setting for probabilistic problem-solving that is relevant and meaningful to students, as probability is one of three mathematical concepts (along with logic and computation) that are foundational to AI [43]. Solving problems with AI often involves reasoning under uncertainties, where probability-based concepts can provide tools to explore and reach optimal decisions. For students, AI provides a modern context to connect probability concepts to real-life situations and provides unique opportunities for transdisciplinary learning that can advance student understanding of both AI systems and probabilistic reasoning.

Until recently, there was very little knowledge and research into how to introduce AI to the K-12 population [54]. One approach to bring AI to the K-12 classroom that has shown promise in other STEM disciplines is digital game-based learning (DGBL). Since the early 2000s, much evidence points to the efficacy of game-based learning in promoting student learning [18, 31], particularly of problem-solving skills (e.g., [47]). Game-based learning has been well studied in its application in math education as well. There is a wealth of literature on designing in-game activities that integrate with learning objectives [5, 9, 17] and out-game teacher's guidance to support students learning in the games [24] to achieve measurable learning outcomes [4]. However, there is very little research into using game-based learning for AI education for the youth [28, 16], given the research field of K-12 AI education is still in its infancy. Designing game-based environments with AI problem-solving offers a great opportunity to both build on and contribute to the existing knowledge of how to integrate math and AI education in K-12 classrooms through technological innovations.

In this paper, we discuss the design of an educational game, *The 7^{th} Patient*, to illustrate probability concepts in AI algorithms and to provide an environment to support the reciprocal development of math and AI skills. Section 3 describes the games' learning objectives in mathematics, particularly independent and conditional probability. Section 4 describes how we designed the game's pedagogy around Bayesian networks [39]: identifying variables, constructing the network with probability tables, performing inference, and decision-theoretic reasoning. Section 5 describes the results of a study of the games' efficacy when used by high-school students.

2 Related Work

2.1 K-12 AI Education

Recent efforts to investigate the integration of AI into K-12 schools have begun by defining AI literacy [30] and developing curricula and guidelines [13, 34, 48], for elementary [25], middle [59], and high schools [10]. Researchers in youth AI education have been experimenting with teaching AI, including machine learning [41, 61] and ethics [12], through conversational agents [29, 49], deepfakes [3, 2], dance [38], robotics [55], and games [27, 35]. Youth AI education is taking place in both formal and informal settings (e.g., [36, 52]), at the state level (e.g., [6]) and around the world [57, 58], including Europe [22, 1, 7], China [46, 60], Thailand [44], Australia [19], and Israel [45]. While most K-12 AI education focuses on the topic of machine learning, some pilot research has taught foundational concepts of AI (e.g., [27, 35, 52]). Each project however, only had the capacity to teach a small set of the foundational AI concepts.

2.2 Game-based learning

Educational games have demonstrated efficacy in building problem-solving skills [47] and facilitating both cognitive and affective dimensions of learning [40, 37, 53, 33]. With inviting settings, expressive characters, and compelling virtual worlds, educational games make learning experiences effective and engaging for learners [56, 32]. Digital games have been applied to building computational thinking [42] and teaching AI for K-12 learners [27, 8, 35]. The efficacy of educational game depends on how the learning content is integrated and how it allows students to interact with the content in a way that would be unavailable or difficult in classrooms [5, 9, 17]. Researchers have proposed design principles, such as situating learning activities within the game story, designing characters that students will take on, making games pleasantly challenging, and scaffolding reflections [14, 15, 51]. There is a wealth of literature on designing in-game activities that integrate with learning objectives [5, 9, 17] to achieve measurable learning outcomes [4]. While there is a booming educational game industry that caters to learners from preschoolers to lifelong learners, most of the evidence-based research focuses on games designed to be integrated with classroom instructions (e.g., [27]) or to be used outside of the classroom with educator facilitation (e.g., summer camps, afterschool programs). There is a lack of educational games (both formal and informal) that build on evidence-based research to help youth learn about AI and ethics.

3 Lessons in Probabilistic AI

The game's curriculum includes seven lessons:

Lesson 1: To support an asset-based approach, Lesson 1 begins by engaging students in both thought experiments (e.g., what does it mean to say something is likely to occur?) as well as simulated probability experiments (e.g., with coins, dice) in the game. The objective is to surface and prime students with questions and hypotheses about probability that can be interrogated through the lessons that follow.

Lesson 2: Students learn to identify relevant events in, for example, medical scenarios by cataloging both the relevant conditions (e.g., a patient has gout) and outcomes (e.g., the patient's foot hurts).

Lesson 3: Bayesian networks are introduced as a graphical visualization of the conditional independence relations among the events identified in the last lesson. Students are guided to gather data in the game's open world, to use the data to determine the causal influences between nodes, and to translate causal influences into directed links between nodes.

Lesson 4: Students gather data on prior and joint probabilities by, for example, recording how often gout occurs in the open world and how often someone suffers from gout and has a bump on the ear. Students are then guided to enter the frequency counts into a prior or a joint probability table.

Lesson 5: Students learn how to calculate conditional probabilities from joint probability tables and complete the conditional probability tables that quantify probabilistic relationships in Bayesian networks (e.g., the probability of foot pain if the patient has gout).

Lesson 6: This lesson introduces Bayesian network inference by enumeration, whereby students compute probabilities by applying the addition, multiplication, and Bayes' rule.

Lesson 7: This lesson presents decision theory, which combines probabilities with the utility of events. Students learn to translate their preferences into a utility function, compute expected utility, and use that to make decisions (e.g., make medical diagnoses).

4 Game Design

The 7^{th} Patient is an isekai-esque role-playing game, where students play the role of a modern-day high-school student who, along with their laptop, is suddenly displaced into a fantasy world set in a pseudo-medieval era (Figure 1). To make their way back, the player, with the help of an AI installed on their laptop, learns and uses probabilistic AI to solve problems. The game begins with a series of tasks in the Medical Arc, where students are first introduced with the concepts in probability and Bayesian networks through medical diagnosis tasks. After sufficient progress, the game then opens alternative quests, where the students construct Bayesian networks and apply probabilistic reasoning to solve a variety of problems, e.g., finding the weaknesses of monsters, deciding what crops to plant, or locating a lost cat. The goal of the quests is to help the students practice and transfer what they learned from one domain to the next.

The game design is grounded by the asset-based pedagogy that builds from students' interests and lived experiences to allow them to bring their own funds of knowledge into the learning experiences. The game simulates medical diagnosis tasks, as they are the most common application of Bayesian networks. The diseases simulated in the game are carefully chosen to be familiar to the students. Placing the game in a fantasy era creates a parallel world with problem-solving

Fig. 1. The scene introducing the player to the world of the game

contexts similar to, without mirroring, the modern-day real-world, avoiding evoking students' discomfort when in-game events (too) closely mimic their own lived experiences.

In the experiment of Section 5, students played only the Medical Arc, so we focus on that portion of the game. In this arc, the student proceeds through a series of cases, each prompted by a patient suffering from an ailment whose symptoms are potentially ambiguous. The ailment and symptoms change across the patients, but the Bayesian network structure stays the same. In particular, there is a single root node, corresponding to the patient's uncertain ailment, and two child nodes, corresponding to the possible symptoms. The symptoms are treated as conditionally independent given the parent ailment node, so there is no link between them. We maintain the same dependency structure for tutorial purposes in the Medical Arc, and we leave more complex structures to the other arcs.

Following the progression outlined in the Section 3, the initial patients focus on identifying critical events and the graphical representation of those events in the Bayesian network. In other words, there are no numeric values until we reach Lesson 4. Instead, the students learn about determining the relevant random variables from the descriptions given by the patients in game dialogue. They must then determine which random variables correspond to hypotheses about the patient's possible ailment (which is not directly observable) and symptoms (which are directly observable).

Once the network is constructed, the student must enter evidence based on the patients' description of their symptoms. Figure 2 shows an early patient's Bayesian network, with both symptoms being present (as indicated by the green highlight on the two child nodes). At this point, the student's "AI Assistant" computes the conditional probability of the patient's ailment given the observed symptoms. By having this conditional probability be computed automatically, we focus the student's attention on the building of the probabilistic model and gaining intuitions about how different modeling choices lead to different outcomes from a probabilistic AI system's outcomes.

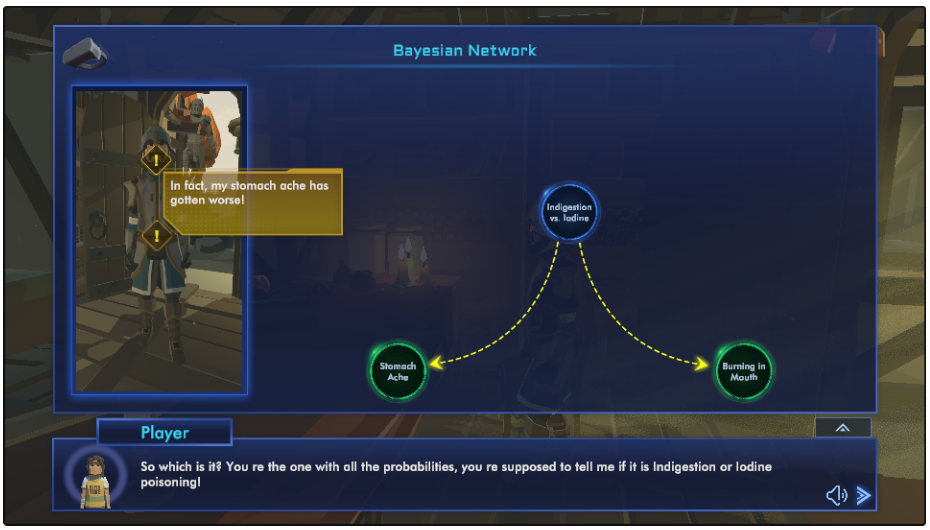

Fig. 2. The Bayesian network for the first patient in the Medical Arc

As the student progresses through the Medical Arc, they are also progressing through the lessons of Section 3. We gradually expose more and more of the internals of the Bayesian network and the AI calculations that come with it. Students first see the probability table on the root node, representing the prior probability associated with the possible diseases. In later patients, they see the probability tables of the child nodes, representing the conditional probability of those symptoms given the possible ailments. Figure 3 shows one such patient, with the probability tables now viewable by the player.

The final patient brings the students to Lesson 7, where they learn about expected utility. Figure 4 shows that patient, with the Bayesian network now extended to include a utility node, corresponding to the relative value of different diagnosis outcomes.

5 Experimental Results

In spring 2024, we conducted an efficacy study of the game with 1000+ high school students. The study protocol was approved by the PI's university's Institutional Review Board (IRB). We also conducted a cognitive interview study

Fig. 3. The Bayesian network for a subsequent patient of the Medical Arc, with conditional probability tables now viewable by the student

Fig. 4. The Bayesian network for the final patient of the Medical Arc, with a utility node now included in the network

with 20+ high school students to gain insight into how they approach the game and the AI and probability problem-solving. We will discuss the game design and findings from the studies in the paper.

Procedure Participating teachers from a school district in the Los Angeles metropolitan area were provided an overview of the game, learning goals, and study procedure a few months before the study began. A few weeks prior to the study, students were given an online parental consent form and a youth assent form. Only students who consented participated in the study. Students were first assigned IDs to protect their identity throughout the study, and then completed the pre-survey online. They then played *The 7^th^ Patient* game online via a web browser. The students then completed the post-survey online. The experimental procedure was approved by USC IRB before conducting the study.

Measures The pre-survey consisted of items about students' demographic background, AI Use Type, Interest in AI, and AI Knowledge. All scales were developed by the research team. The AI Use Type included items such as "AI can be used to solve problems in my community." The Interest in AI scale included questions such as "I want to learn more about AI outside of school." The assessment of AI knowledge and math knowledge specifically focused on the probabilistic AI content covered in the game, in the format of multiple-choice questions. The AI questions were set in the context of solving AI problems similar to those encountered in the game. The questions assessed students' understanding of, for example, probabilistic calculations from word problems in various contexts. In the post-survey, the same items on interest in AI and AI knowledge from the pre-survey were included. In addition to the surveys, game logs were collected. The logs included the in-game click-stream data and responses to in-game prompts.

5.1 Results

1,299 students completed the pre-survey portion of the experiment. 937 students completed the game and the post-survey. Of those who finished, 855 students entered the same anonymized ID between the two surveys, and we examine only those students' responses going forward. Of the students who provided their grade level, 196 students were in 9^{th} grade, 169 in 10^{th}, 258 in 11^{th}, and 184 in 12^{th}. The students ages ranged from 12–20, although all but six students' ages were in the 14–18 range. Of the students who reported a gender, 390 were female, 385 were male, 9 were non-binary, and 10 self-identified as an unlisted identity.

We start by looking at the changes in the students' responses between the pre- and post-tests. The strongest positive results came with respect to their confidence in their understanding of "Bayesian networks" and "posterior probability". Both items received 858 responses, on a 5-point Likert scale, with a mean change of 1.10 and 0.99, respectively. There were 580 and 543 students, respectively, responding with a more positive value on the post-test, with only 37 and 50, respectively, responding more negatively.

There were weaker positive results for the following three questions:

1. I can make sense of probability tables and make decisions based on the information in them.
2. I can see how this game was connected to learning about probability and AI.
3. I can explain how probability and AI are related to a friend.

These three showed mean gains of 0.50, 0.35, and 0.41, respectively, also on a 5-point Likert scale. The number of students responding more positively was on par with the number of students responding with no change.

There was a negative result when asking whether students agreed that "I am interested in learning more about Artificial Intelligence (AI)." The mean change was -0.33, with 332 out of 852 respondents giving a more negative answer in the post-test. While this result is disappointing, it is perhaps not too surprising given that the partial implementation of the game covered only the tutorial aspects of the Medical Arc. Our hope is that the subsequent version of the game, which offers the students a more diverse gaming experience and more freedom of choice, will be more stimulating of their interest.

On the other hand, there was a positive result with respect to agreement with the statement, "I plan to study AI after high school." The mean change was -0.31, with 319 of 853 students responding more favorably in the post-test. Teasing apart the difference in responses to this statement and the previous one is left to future work.

The remaining statements showed only minor changes in response. These statements pertained to talking about AI with their families, taking a course on AI if offered, and believing AI to be relevant to their lives. Further analysis is needed to determine the degree to which ceiling effects were at the root of the static nature of some of these responses.

6 Conclusion

This paper presented a game-based learning approach to illustrate probability concepts in AI algorithms and to provide an environment to support the reciprocal development of math and AI skills. The investigation raises important research questions on how to design in-game problem-solving to support AI and math learning, how to develop narratives to engage students in the examination and reflection of misconceptions of probability, and how to build lessons and instructions around the game activities to support uptake in math classrooms. Evaluating the efficacy of alternate designs, including in the additional arcs other than the Medical Arc described here, provides a methodology by which we can improve current practice in high school probability education by incorporating AI problem-solving that is meaningful and relevant to students.

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