Sick Kitty—Toward Promoting Deductive Reasoning through an Embodied Medical Diagnosis Game

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Abstract: In this paper, we introduce Sick Kitty, a multimodal deductive logic game for primary school children. Sick Kitty situates students as experts with the task of disease diagnosis. They are equipped with a mix of simulated medical tools and a lively stuffed kitty as patient. Sick Kitty is an untraditional method to teach reasoning in classrooms. The main contribution of this work is the design of the multi-modal logic game that promotes scientific reasoning and inquiry. We expect that Sick Kitty will promote the development of deductive reasoning ability for students.

Introduction

The classroom offers the opportunity to teach children how to reason and use reason as a tool for learning. Moreover, children can be taught to value their capacity for thinking along with how to learn from others and share in inquiry. Much of our current interest in improving critical thinking among students stems from their developmental need for higher-order thinking ability coupled with the growing economic and political urgency for students as critical thinkers (Idol, Jones, & North Central Regional Educational Laboratory, 1991).

We have focused our efforts on improving deductive logic. Deductive logic plays an essential role in all aspects of critical thinking (Ennis, 1971)Ennis and his associates discovered that primary children vary greatly in their degree of competence in conditional logic, and the principles differed considerably amongst themselves in their degree of difficulty. The evidence here reported is taken to count rather strongly against Piaget’s claims that children under 11–12 years of age cannot handle propositional logic and cannot reason correctly from premises that they do not believe. Conditional logic knowledge correlated fairly highly with Wechsler verbal IQ, moderately with socioeconomic status, and weakly with dwelling area. Boys and girls appeared to be about equal in logical ability.”,”DOI”:”10.1007/BF02137796”,”ISSN”:”0826-4805, 1573-1790”,”shortTitle”:”Conditional logic and primary school children”,”journalAbbreviation”:”Interchange”,”language”:”en”,”author”:[{“family”:”Ennis”,”given”:”Robert H.”}],”issued”:{“date-parts”:[[“1971”,6,1]]},”accessed”:{“date-parts”:[[“2013”,12,9]]}}}],”schema”:”https://github.com/citation-style-language/schema/raw/master/csl-citation.json”} . Fluid intelligence refers to the use of mental operations to solve novel problems (Primi, Ferrão, & Almeida, 2010). These mental operations include extrapolating, transforming, and classifying information; drawing inferences; identifying relations; constructing concepts; comprehending implications; solving problems; generating and testing hypotheses; and inductive and deductive reasoning (Barkl, Porter, & Ginns, 2012). Sick Kitty is a learning activity aimed toward the development of deductive logic in children 10–12 years of age.

Sick Kitty situates students as experts with the task of disease diagnosis. They are equipped with an Android smartphone (or tablet), Sick Kitty application, and a modified stuffed kitty as patient. The Sick Kitty application drives the diagnosis experience via simulated medical tools and a chart for tracking diseases and symptoms. Sick Kitty differs from other research regarding in-classroom logic training as it relies on the use of children’s sensory abilities and technological interactions to solve game-based deductive logic puzzles. First, this paper explores the theories regarding children and reasoning followed by a review of prior work in this area. We then introduce our approach, Sick Kitty, and detail the design and rationale, system architecture, and planned evaluation.

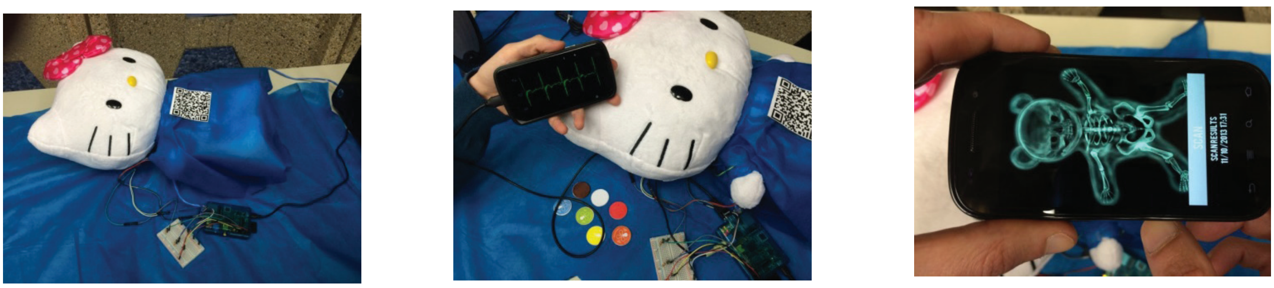

Figure 1: Sick Kitty Prototype (far left) and the ECG (middle) and X-Ray (right) to detect symptoms

Background

Reasoning Tasks

The nature of deductive logic is the ability to predict the outcome of a particular event given a general principle. The Sick Kitty Project allows for primary school students to develop their deductive logic in a trial-and-error fashion, an approach that is customary for their operational stage of development (Ennis, 1975). Moreover, the project emphasizes the application of this knowledge to real world problem solving, that of medical diagnosis.

Ennis' work evaluates children's abilities to assess the conclusions of deductive arguments in the form of the basic principles of class and conditional reasoning. The format of questions is as follows:

> Suppose you know that
>
> Premise 1
>
> Premise 2
>
> Then would this be true?
>
> Conclusion

The possible responses are "A. YES," "B. NO," and "C. MAYBE." This type of reasoning is essential to the activity we present.

Stages of Reasoning Development

The well-known work of Jean Piaget regarding cognitive development contends that children between 10-12 years old often struggle to attain proficiency in deductive logic (Inhelder, Piaget, Parsons, & Milgram, 1958). However, other studies show that instruction in certain principles of deductive reasoning, such as modus ponens, could begin as early as the fourth grade and yield meaningful results (Barkl et al., 2012; Roberge, 1970).

Shapiro's work shows that elementary-school children have considerable success in recognizing logically necessary conclusions. However, primary school children, do not show the same success in their ability to distinguish between a logically necessary conclusion and a statement which is not logically necessary (Shapiro & O'Brien, 1970).

Sabinin shows that even preschool aged children can perform logical reasoning. Activities geared toward this group must have non-complex tasks, few things to remember, and few steps. A familiar context for the reasoning is also ideal for this age group. As students grow, their logical reasoning complexity increases along with their familiarity with varying contexts. Moreover, they learn to visualize and imagine more accurately (Sabinin, 2013).

Related Work

During the last several decades, there have been a number of empirical investigations focused on the development of logical ability in children (Barkl et al., 2012; McCarthy-Tucker, 1998; Roberge, 1970; Sabinin, 2013). However, none of these studies have implemented the use of a multimodal game for student training, moreover, much of the emphasis is placed on the instructor delivering a set curriculum of materials.

Roberge's work contributed to theory concerning the development of logical reasoning ability in children. Roberge offers insight on the grade levels at which specific principles of class and conditional reasoning might be taught given children's developmental patterns. His results suggest that formal classroom instruction in deductive reasoning, such as modus ponens, could begin as early as the fourth grade (Roberge, 1970).

The CTC program is a guided-learning paradigm in which students are talked through problems, asked questions, encouraged to verbalize their solution strategies, and practice these skills over time. Barkl et al used the CTC program to test its effect on student reasoning and mathematics achievement. The study compared the CTC program delivered to individuals, to groups, and to a no-treatment control group. Students performed cognitive abilities test, inductive reasoning test, deductive reasoning tests, and tests for mathematics achievement (Barkl et al., 2012). The results showed that both individual and small group-based training on the CTC program enhanced inductive and deductive reasoning ability.

The work of Sabinin follows a more playful approach to logic learning. Students are equipped with "Smart Cookies", a logic puzzle, and teachers follow a supplementary curriculum for puzzle instance creation and resulting discussion questions. Sabinin's research emphasizes the importance of visualization and reasoning-and-proving. Students are able to work individually, in groups, or as a class and the puzzles cover a full range of difficulty to accommodate many levels of student preparedness and aptitude (Sabinin, 2013). Lastly, Sabinin contends that the availability of feedback from the activity as opposed to the teacher develops independent checking for students.

McCarthy-Tucker investigated whether teaching formal logic to adolescents in a U.S. public high school ameliorated their ability to think critically as measured by both standardized ability tests and student self-perception (McCarthy-Tucker, 1998). Results suggest that adolescents instructed systematically regarding components of logical reasoning improved their thinking skills. These components included the purposes of reasoning, conditional reasoning, antecedents and consequents, deductive, inductive, hypothetical-deductive, and analogical reasoning, and a discussion of laws of probability among other topics. The study also found that relating the activities to realistic events, and student concerns and questions was an essential part of instruction.

Design Rationale

At its core, Sick Kitty is a logic puzzle game with visual, auditory, and tactile presentation layers embodied in a stuffed animal, Sick Kitty, and further played out on a mobile device. Our hope is that the multimodality will be appealing to the target audience while increasing learning gains. Further, the distinct separation of layers bodes well from a design perspective and helps us develop each of the components with a high degree of autonomy.

Sick Kitty is a team game with a trial-and-error approach to play that is somewhat similar to the classic board game 'Guess Who?' ("Guess Who?," 2015). In 'Guess Who', two players take turns in deciding which card their opponent has by a process of elimination using questions such as 'Do they have brown eyes?'. In Sick Kitty, the teams examine a tangible patient, Sick Kitty, for various symptoms and, given a the diagnostic interface which correlates symptoms to illnesses, teams are able to discover Sick Kitty's illness. The game accommodates varying levels of difficulty via probability reasoning. For example, an illness may have multiple symptoms, however all of them may not occur 100% of the time. This requires students to use additional logical reasoning and perhaps perform additional diagnostic tests.

We also enhance gamification by introducing a scoring element to determine team success. A monetary value is attached to a symptom's diagnostic test. This encourages students to use the most efficient combination of steps to reach a diagnosis. For example, an X-ray could cost $1000 while a physical exam could cost $50. Students receive these costs at the onset of the activity. The scoring element is also especially useful for teachers if evaluation of performance is required.

Another key design decision for Sick Kitty is the use of fictional symptoms and illnesses. As medical diagnosis is a real domain, we recognize that students may have varying levels of exposure to medical trauma that may cause negative emotional responses. We avoid these parallels through our fictional medic world. An additional benefit to this approach is the ability to easily make new illnesses and symptoms to further accommodate student levels of learning.

Prototype Overview

During the Sick Kitty learning experience, students aim to diagnose Sick Kitty's illness. The core activity is a deductive reasoning and elimination game that focuses on deciding what symptoms Sick Kitty exhibits and what the most likely illness could be given those symptoms.

At the start of the game, students form teams. Each team is given a Sick Kitty, which has been initialized by the teacher to have a particular illness and certain symptoms. The team is also given a mobile device equipped with set of tools, including an X-ray scanner, ECG and diagnostic interface and shown in Figure 1 and Table 1. On the diagnostic interface, each illness's symptoms are marked in up to three ways:

- must have symptom
- (*optional*) can have symptom
- cannot have symptom

Given this information, the team must systematically eliminate potential illnesses and narrow down to the most likely illness which is distressing Sick Kitty. The diagnostic tests support different modalities for interaction. For example, a student performs a heart rate test by measuring Sick Kitty's pulse via touching her wrist and counting the number of vibrations in a tactile fashion. Table 2 shows a list of all symptoms, how the students test for that symptom, and the type of technology we use to create a compelling educational game experience.

Disease	Symptoms										
	Coughing	Sneezing	Sore Belly	Sore Throat	Fast Pulse	Slow Pulse	Rocky Kidneys	Funny Leg	Slow Heart	Fast Heart	Funky Heart
Pumpkaboo	✓	✓			✓						
Aromatisse											✓
Scatterbunk	✓	✓		✓	✓		✓		✓		
Chezpin			✓			✓				✓	
Volcarona	✓	✓		✓							✓
Ulgamoth			✓			✓		✓			
Golurk			✓			✓	✓		✓		
Cost	Free	Free	$100	$200	Free	Free	$1,000	$2000	$1300	$1300	$1300

Figure 1 - Sample Diagnostic Sheet

Table 1: Sample Information from Diagnostic Interface

The activity ends when the team submits a correct diagnosis. At this time, the Sick Kitty system notifies the teacher of various metrics including the diagnosis, play duration, and the number of diagnoses made in a separate administration console. Though the primary evaluation metric is cost, time to solve the puzzle may also be a good indicator of performance gains.

The support for different levels of difficulty ensures that Sick Kitty can be reused for an extended time within the classroom. The teacher or administrator has the ability to set the number of diseases, symptoms, and likelihood of symptoms present. Initially, teachers may provide students with a small set of diseases and symptoms, along with more deterministic symptoms. As students become more proficient in their reasons, the teacher can add more symptoms, alter probabilities, and in turn increase difficulty.

Name	Tool	Technology
Groaning, Coughing, Sneezing,	Auditory	Speaker
Ticklish, Sore Throat	Press Kitty's throat	Button
Sore Belly	Press Kitty's stomach	Button
Pulse	Touch Kitty's wrist	Motor
Rocky Kidneys	Ultrasound (*mobile*)	NFC
Funny Leg	X-Ray (*mobile*)	QR
Slow/Fast/Funky Heart	Electrocardiogram (*mobile*)	USB

Table 2: Symptom Details

System Implementation

Sick Kitty uses a distributed, modular architecture. Broadly speaking, the system is split into two pieces: (a) a single server application and (b) external devices supported by a well-defined API. The server application is responsible for the state and actions of the physical Sick Kitty. Each Sick Kitty will have a single server application and up to 16 different external devices that can dynamically connect to the server via Bluetooth. The API allows for these external devices to interact with the server application via synchronous message passing. This works similarly to web requests; a message structure is marshalled into XML, where it is sent to the server, it is then processed, and then an acknowledgement with some response is sent back to the device. A full lifecycle of the applications can be seen in Figure 3.

Server

The server is a standard desktop Java application running on a Raspberry PI (Halfacree & Upton, 2012). On startup, the server application initializes with two configuration files: a list of illnesses, and a list of symptoms. At this point Sick Kitty is put into a default state of no active game. A game activates via a message from an external device, the administration console, which dictates Sick Kitty's illness.

Once Sick Kitty is activated with the type of illness, the game state loads the appropriate symptoms. The symptoms are assigned based on the illness configuration. When the symptom list is finalized, the game loop will execute at a rate of 20 times per second. Each call of the game loop will address three important functions: 1) process external messages, 2) update Sick Kitty's state, 3) and give appropriate output.

To begin, the server processes messages from the external devices. This is done by querying each active Bluetooth port, reading, processing, and then writing any response in XML. The main messages include:

- Starting a new game, given an illness
- Getting a list of all illnesses
- Getting a list of current symptoms which Sick Kitty is suffering from
- Setting an antidote
- Make a charge to Sick Kitty's account

Next, the server updates Sick Kitty's game state. Sick Kitty will hold numerous attributes that describe the current game state. For example, an internal state variable is the value of the heart rate timer. There are also some external stimulus' that affect Sick Kitty's state such as button presses. Finally, Sick Kitty produces output given her current state. Outputs include Sick Kitty's pulse vibration and sounds in the form of groaning or sneezing.

Apart from the Bluetooth interaction with external devices, the server also handles I/O via the Raspberry PI's GPIO pins. The general IO pins can be connected to simple electronic components, such as buttons and switches. Sick Kitty uses the GPIO for responsiveness to push sensations and tactile feedback generation. For example, Sick Kitty winces if pressed on her stomach while attributing the "Sore Belly" symptom. Additionally, a vibrating coin motor in Sick Kitty's wrist is connected to the GPIO pin. A timer turns the motor on and off at determined intervals to give the illusion of Sick Kitty's pulse.

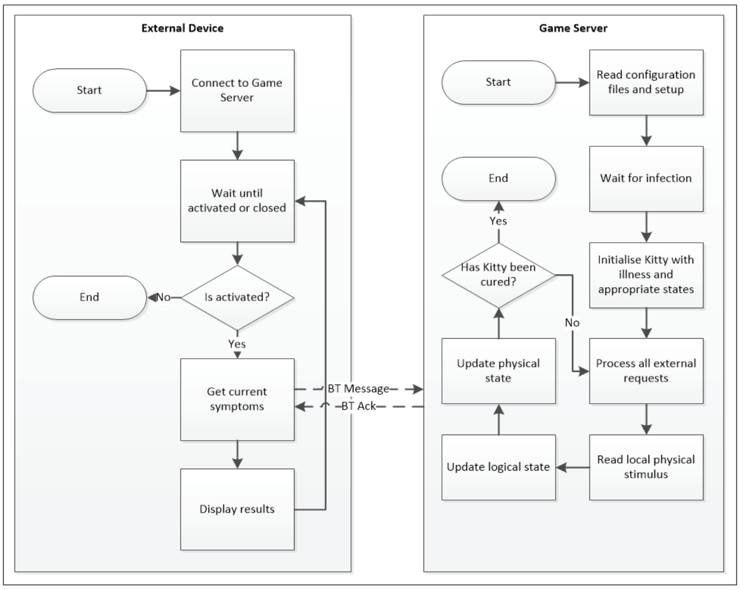

Figure 3 – Example System Lifecycle

Figure 3: Example system lifecycle

External Devices

External devices serve as additional interfaces to Sick Kitty. We employ our Sick Kitty android application that supports two modes: (a) administration console and (b) student interface, which contains a series of student tools used to diagnose Kitty's illness.

The administration console provides the teacher with game setup and monitoring privileges. The console allows the teacher to start new games with specific illnesses, as well as view details about the current game, such as the duration, real-time costs, the number of diagnoses and most recent diagnosis.

The student interface provides a consistently embodied experience to students that naturally replicates medical diagnosis. A student diagnosis instrument will acquire the current symptom list, charge the team account for instrument use, and provide feedback that gives insight into Sick Kitty's illness.

An example of a student instrument is the Ultrasound tool. This tool depicts if Sick Kitty is suffering from the symptom 'Rocky Kidneys'. Students must slowly swipe the tool over Sick Kitty's kidney area to activate the Ultrasound test. The tool is detected once the device's NFC reader nears the RFID tags stitched into Sick Kitty. Once read, the tool displays an appropriate image based on the symptom list and the students can then deduce the presence or absence of the symptom.

Future Work & Evaluation

As, stated the goal of our work is to explore how a multi-modal game can improve primary school students' reductive reasoning ability. While we successfully implemented the overall system design and functionality, we still intend to implement the game in a local Chicago elementary school. To evaluate improvement in the students' development of deductive logic, we will use a derivative of the Cornell Conditional Reasoning Test. The tests are based on the same principles of deductive logic we hope to enhance through Sick Kitty (Ennis & Paulus, 1965).

We are also interested in evaluating students' level of engagement in the activity. We will accomplish this through a Likert scale survey of satisfaction. Finally, we would like to analyze students' logic strategies. The questions we wish to analyze include: what kinds of strategies are used, and whether the strategies change over time. All these questions are important in order to understand the student's learning process and how to improve learning gains for the game.

Lastly, there exist a large number of possibilities that can be incorporated into future iterations of the design to further enhance and improve the activity. For example, speech recognition and generation can be added to provide another mode of interaction.

Conclusion

We achieved each of the desired core functionality components for first prototype iteration of the Sick Kitty game. Functionality includes:

- A large stuffed kitty with the following enhancements:
  - Pressure sensors to detect touch at stomach and neck
  - RFID tags for proximity detection with an NFC enabled device
  - Vibrating coin motor on wrist
  - Speaker output capability
- Android application with administration console, diagnostic interface, and the following tools:
  - X-ray scanner
  - Electrocardiography (ECG)
  - Ultrasound
- Game server
  - Definitions of illnesses and symptoms given in an XML file
  - Kitty reacts to stimulus as appropriate to its illness and ailments
  - Diagnoses strategy score

The current prototype version of Sick Kitty is fully functional and promising for future classroom deployment. Sick Kitty accommodates varying levels of deductive learning and can become a valuable tool for classroom and individual logic development training.

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