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Little Genius: An Experiment in Internet of Tangible Learning Things

Imran A. Zualkernan
Comp. Science and Engineering
American University of Sharjah
Sharjah, UAE
izualkernan@aus.edu

Fadi Aloul
Comp. Science and Engineering
American University of Sharjah
Sharjah, UAE
faloul@aus.edu

Eilaf Algebail
Comp. Science and Engineering
American University of Sharjah
Sharjah, UAE
g00058145@aus.edu

Mohamed El Refaay
Comp. Science and Engineering
American University of Sharjah
Sharjah, UAE
b00057613@aus.edu

Abdulkarim Ali
Comp. Science and Engineering
American University of Sharjah
Sharjah, UAE
b00053674@aus.edu

Omar El Sabaa
Comp. Science and Engineering
American University of Sharjah
Sharjah, UAE
b00057603@aus.edu

***Abstract*— The Internet of Tangible Things (IoTT) provides new opportunities for building technology-enhanced learning systems that wirelessly connect tangible sensor data to remote learning services. This paper presents the design and implementation of an IoTT voice driven learning platform that uses Amazon Alexa along with sensor-enabled wireless dice to build tangible and interactive math games for kindergarten and primary school children. The wireless dice used sensors in a 9-axis IMU to accurately detect the face each die falls on and sent this information to Amazon Web Services (AWS) using the MQTT protocol using AWS-IoT service to enact arithmetic learning scenarios. An initial evaluation shows that most children from ages 5 to 9 enjoyed playing with this system. Half the children liked everything about the game, and they all liked the concept. This game is a first step towards a new genre of educational learning technology called Internet of Tangible Learning Things (IoTLT).**

Keywords*— *tangible learning, Alexa, arithmetic learning, gamification, MQTT, AWS-IoT, edutainment, IoTT, IoT

I. Introduction

Internet of Tangible Things (IoTT) [1] is about connecting tangible interfaces and devices using the Internet. For example, user's manipulation of a physical ball can be directly incorporated into decision-making application across the cloud. IoTT applications allow users to connect directly with the physical world on one end, interact with remote internet-based services, and to collaborate with other users across the Internet. Using tangible interfaces to facilitate learning has been proposed earlier (e.g., [2]). More recently, others have proposed interfacing and augmenting serious games with IoT technologies [3] [4] [5]. However, to our knowledge, very little has been done in creating IoTT-based tangible learning systems. In addition to using tangible objects, doing so will enable the use of Internet-based services like Alexa and Siri, and will also allow learners to participate in tangible learning activities that transcend geographical boundaries. Hence, this new class of IoTT technologies called Internet of Tangible Learning Things (IoTLT) incorporate tangibility and remote social learning simultaneously.

This paper presents the design, implementation, and an initial evaluation of an IoTLT-based arithmetic learning game called Little Genius. The game consists of tangible physical dice to pose arithmetic problems to children and incorporates Amazon Alexa and AWS-IoT to enact voice and learning services.

II. System Design

Fig. 1 shows the overall system architecture for Little Genius. A child communicates with Little Genius using Alexa. The child uses two tangible numbered dice to solve arithmetic problems. Each component is described next.

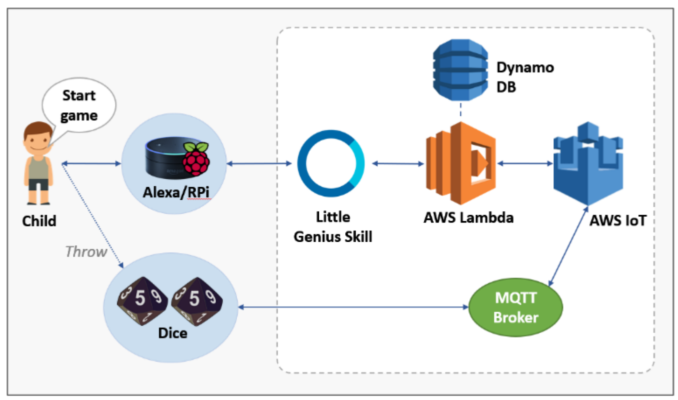

Fig. 1. Little Genius: System Overview

A. The Dice

As Fig. 2 shows, two 17 cm, ten-sided dice were custom built for the game. Each face of a die was labelled with numbers from 0 to 9. In addition, each face had an LED to indicate the state of the dice.

Fig. 2. Two 10 sided Tangible Dice

The die hardware consisted of an ESP32 board [6], an Inertial Measurement Unit (IMU) [7], 10 LEDs, and a rechargeable battery to power the hardware. ESP32 used a Dual-core Tensilica LX6 microprocessor and supported WIFI through an

Integrated 802.11 BGN WIFI transceiver. The 9-Degrees of freedom (9DOF) IMU including 3-axes accelerometer, gyroscope, and magnetometer, was connected to the ESP32 board inside the die. Once dice were rolled by a child, the IMU sensors detected variations in each of the three axes. Using a custom algorithm implemented as a C program, the ESP32 in each die used the sensors' raw values to calculate which faces the dice landed on. The faces that dice landed on were then communicated to the game skill on Amazon Web Services (AWS) using the MQ Telemetry Transport (MQTT) protocol [8] over WIFI. Each die used the MQTT protocol to publish and subscribe data from and to the Alexa skills described later. This allowed the game skill on Alexa to control the state of each die being manipulated by children.

B. *Alexa Hardware*

To interact with Alexa, a Raspberry PI and the Microsemi AcuEdge™ Development Kit was used from which a child spoke to and received instructions from a connected speaker.

C. *AWS IoT Services*

Amazon Web Services (AWS) Alexa's skills kit was used to build the game skills using AWS Lambda functions. AWS-IoT was used to communicate with the ESP 32 boards using MQTT protocol and AWS shadows. Dynamo Database (DB) on AWS was used to store learner information and gaming results.

III. GAME FLOW

Fig. 3 shows the sequence diagram of the 'Play Game' use case. An example of a typical dialogue between a child and the game is shown in Fig. 4. As Fig. 4 shows, a child interacts with Little Genius through conversation. Little Genius asks the child which Math skill they need to practice. Upon choosing a skill, the Math skill on AWS creates a learning task for the child. For example, for addition, Alexa asks the child to throw both dice on the floor. When the dice land on the floor, the child is asked to add the two numbers appearing on the top faces and to speak their answer back to Alexa. The AWS skill then checks their answer and provides verbal feedback in the case of correct or wrong answer. In the scenario shown in Fig. 4, the AWS skill posed a problem. However, another child across the Internet can also pose problems to be solved by another child using two similar dice connected to the same service.

IV. EVALUATION DESIGN

Ten children participated in the initial evaluation (6 boys, and 4 girls). Seven children were 5 years old, two were 7 years old and one was 9 years old. Each child was given some time to explore the dice before a game was started. This was done to reduce the likelihood of the children exploring the dice during the game and then getting distracted. A laddering evaluation framework [9] was used. Accordingly, after a child played a game, they were asked the following questions in a sequence:

1. What do you think about the game?
2. What do you like/dislike about the game and why?
3. What do you like/dislike about the dice and why?
4. What do you like/dislike about the voice feedback and why?

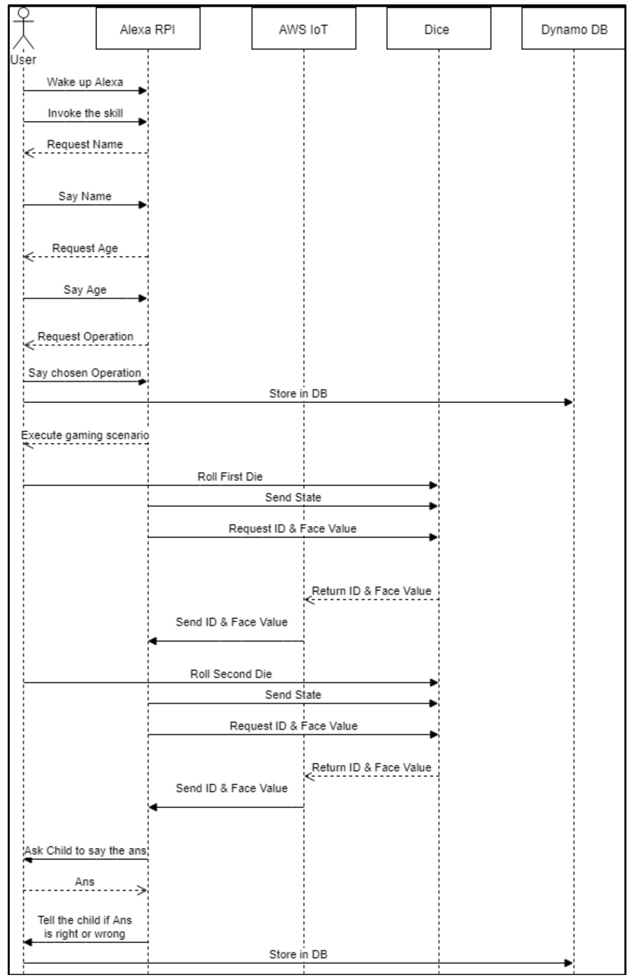

Fig. 3. Play Game Sequence Diagram in Little Genius

Child: Alexa, tell Little Genius I want to play
Alexa: Welcome Little Genius, if you are up for a challenge, say your name
Judy
Your name is Judy, right?
Yes
And how old are you Judy?
I'm 6
You are 6 years old, correct?
Yes
Alright, and which math operation would you like to practice today?
Addition
You selected addition, right Judy?
Child: Yes
Hooray! Your game is now ready. When you want to start just say "I am ready"
I am ready. *<The two dice start blinking>*
Throw the first cube <pause> Now throw the second cube <pause> Add the face values of cube one and cube 2. When you are ready say the answer
5
Your answer is correct. *(Whispers) High five little genius!* If you want to play again, just say "I am ready"
I am ready
What is the answer for 3+5? Use the blinking cube to show your answer.
(Whispers) That was so close! but your answer is incorrect. If you want to play again, just say "I am ready"

Fig. 4. Play Game Sample Game Play Scenario

The same questions were individually asked in positive and negative forms to ensure that responses taken from the children correctly depicted how they felt. Furthermore, whenever a question was not answered confidently, it was repeated at the end to ensure that the child held the same initial response. Non-verbal reactions of children were also taken into consideration while recording their responses as these can reveal additional information. This process resulted in a list of connected elements that revealed the child's personal values. The process also made it easier for children to understand how they felt about the game and hence, helped them provide more accurate answers. The questions were phrased in ways that considered the children's ages and the possibility of them feeling uncomfortable and not replying accurately; children can sometimes provide wrong answers if they feel that this is what an adult wants to hear. Questions were rephrased whenever this situation was identified. Finally, it should be noted that some children did not speak English as a first language, and this might have had an effect on some outcomes in the feedback.

V. Results

Responses from the children were mostly optimistic. They enjoyed the game and appreciated the dice design and the voice interface (Alexa). All children expressed positive responses when asked what they thought of the game. Most of them said they liked the game and others described it as either 'good', 'nice', or 'fun'. Generally, younger children's comments focused more on the tangible dice, and some were curious about where Alexa was. Older children's comments elaborated more on the experience of the game and what they would like to have added to it.

When asked what they liked about the game, some children indicated that it was a new source of fun for them. Others said they liked playing the game and liked the numbers on the dice. When they were asked what they disliked about the game, 50% of the children said they disliked nothing. Table I shows a summary of the children's responses on what they disliked about the dice.

TABLE I. Summary of Game Evaluation Responses

Percentage	Disliked about the dice	Reason
20%	Size	Wanted it to be smaller
50%	Nothing	-
10%	Two dice	Wanted only one die
20%	Number 0	Dislike the number's color

As seen from Table I, some children disliked the size of the dice which would not be a problem for adults considering their palm sizes, but the children preferred to have smaller dice. Two children did not like the color of number 0 (gray), and one child would have preferred a single dice. The children who participated in the evaluation had no previous experience using Amazon Alexa as a voice interface; some children may have used voice assistants before such as Siri but had never interacted with Alexa. This seems to have enhanced their interest to discover Alexa as observed from their reactions. 30% of the children said they liked the loudness of the voice. Furthermore, some appreciated the verbal feedback from Alexa on their answers at the end of the game. Some children disliked the fact that Alexa would take some time to reply back. This could be due to the effect of the Internet speed in the field as it was not seen as an issue during lab tests. In summary, most feedback collected from children was constructive and could be applied to further improve the gaming experience for children.

Finally, from the feedback, the game satisfied five out of the eight enjoyment elements; game can be completed, game has clear goals, ability to concentrate, sense of control, and immediate feedback [10].

VI. Conclusion

As children are exposed to technology in their everyday life and are already interested in exploring how things work, IoTLT technology provides unique affordances that can be utilized to improve learning for younger children. This paper demonstrates that it is fairly easy to put together IoTLT learning experiences by using off-the-shelf sensors and microcontrollers and integrating these with Internet-based services like Alexa and AWS-IoT hosted on the Cloud. Finally, factors such as the Internet speed and voice quality could be enhanced to guarantee a more seamless learning experience.

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