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Color Sensing AR-Based Approach for Supporting Vocabulary Learning in Children

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Abstract—**Recent emerging technologies have demonstrated a great ability in enhancing the language learning performance in general and vocabulary learning in particular. In this respect, technologies such as Internet of Things (IoT) and Augmented Reality (AR) can make the educational systems more attractive, and thus have enormous positive effect on enhancing the learning performance for young beginners with regard to new vocabularies. In this paper, a color-sensing approach is proposed for supporting vocabulary learning in children using AR and IoT. To facilitate the users' interaction with the system, a tangible user interface capable of visualizing AR concepts is developed. Children can point the color sensor to real world colors and then are provided with the corresponding animations and multimedia content that teaches colors in Spanish language. By conducting experiments on elementary school children, the impact on pupils performance in learning Spanish language vocabularies is assessed using Paired T-Test. Moreover, the usability and accuracy of the proposed color-sensing system is also evaluated. Experimental results show that the proposed approach is quite promising particularly for upgrading performance of vocabulary languages in children and is equally applicable to learning any kind of object sensible in reality.**

Keywords—Learning performance; usability; evaluation; AR, IoT; vocabulary learning; color sensing.

I. INTRODUCTION

The past decade has seen a renewed importance of educational technology systems to provide impressive and effective content in an interactive environment capable of enhancing multisensory learning. Within the existing technologies appropriate for this purpose, Augmented Reality (AR) and Internet of Things (IoT) seem to be quite useful. By augmenting text, video, audio or 3D objects to the multimedia contents through Tangible User Interfaces, the educational concepts become more perceptible even for students with intellectual disabilities and autism [1]. A variety of works have been done to apply these technologies to a wide range of scientific domains such as mathematics [2], biology [3], etc., and besides that, language learning in general and vocabulary learning in particular [4].

The motivation behind our approach is the multisensory ability in improving learning performance by creating efficient interaction to the educational process [5]. In this regard, it is highlighted

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that informative cues within the visual modality can facilitate learning in primary school by influencing the children's bilingual development and intercultural awareness [6]. Another research work on investigating the effects of visual, auditory, and haptic distraction on reading, shows that reading performance is most affected by auditory distraction [7]. A major motive in our method is the use of colors for interaction, discovery and learning. A number of studies have investigated the effect of color-coding on learning performance. Preliminary studies [8] found out that color-coding is an important instructional variable in acquisition. Another recent work also highlighted the importance of color-coding for learning efficiency, especially in learners with low prior knowledge [9].

In this paper, we present a new approach for enriching young children's basic knowledge in vocabulary, using AR and IoT. The ground for implementing our approach is an IoT based prototype system with the capabilities of a low-cost color sensor in human computer interaction. To facilitate the user's interaction with the system, a web application is implemented to present the appropriate AR-based multimedia content based on the detected color. This detected color is the result of analyzing raw sensor data on the server-side. Here, layering the multi-media content onto the physical and traditional book, would make the content more interesting and more engaging for the young learners.

To evaluate the effectiveness of the proposed approach, we considered children's learning performance through teaching "color" vocabularies in the Spanish language.

II. RELATED WORK

Many researchers have focused on the impact of multisensory perception and interactions on learning in general [5], and language learning in particular [6, 7].

Within this scope, some research studies demonstrated that AR techniques within IoT environment are able to enhance student's interest and concentration based on transferring sense of reality, novelty, playfulness and entertainment as well [10]. Here, the fundamental role of IoT is to facilitate interaction and collect useful data from the educational environment.

Within the scope of language learning, a variety of research works have been done, which try to enable pupils learn concepts of vocabularies in different environments. For instance, there exists a research work using AR as a type of multimedia (including text, sound, images, animations and 3D objects) situated in authentic environment for Filipino and German vocabulary learning. Results of evaluation show that AR may lead to better retention of words and improve students' attention and satisfaction [11]. Another research exists which shows that applying AR under visuospatial bootstrapping (VSB) can eventually improve vocabulary learning in a second language [12].

In language learning domain, there is another research work based on speech-enabled AR tool for non-native students to learn English as a foreign language. In this research, the effectiveness of combining AR and speech recognition was evaluated measuring knowledge gain and enjoyment as two essential factors [13].

It is interesting to see that AR is quite able to motivate specifically younger children in kindergarten or primary school to learn a foreign language. For instance, in Peru, an AR mobile application was used for improving the learning of vowel usage and numbers for kindergarten children [14], while in Thailand marker-based AR cards were used for the purpose of teaching English in primary schools [15]. Another example of using AR application to teach English is "Magical Animals", which was developed to teach animal names in English language to kids whose native language is Turkish [16]. There are also various embodied learning types to influence learning English as a foreign language [17].

Due to the rapid use of IoT for educational purposes, it is recommended in some research works to apply IoT alone, or together with AR, for vocabulary and Language Learning. Here, the benefits are mostly related to streamlining the creation of task-based language learning scenarios [18]. Another research work in this scope refers to an immersive language learning environment for young children, created to acquire multiple languages utilizing robots and IoT-based toys based on a framework consisting of some pedagogical considerations [19]. Ubiquitous mobile learning equipped with IoT and AR technologies is also a futuristic end point, toward best practices when applied to mobile language learning. As it is seen from these examples, "context" has a significant role in vocabulary learning, and accordingly, the pedagogists and application developers should consider it in providing meaningful and useful AR/IoT-based applications. Moreover, the main challenges in this area are lack of accuracy in overlaying the virtual models on the real images, as well as tracking, capturing and processing images [20]. To overcome this problem, some researchers have worked on deploying sensors in AR/IoT-based interactive learning settings [21] or substitute sensors for improving multisensory perceptual learning.

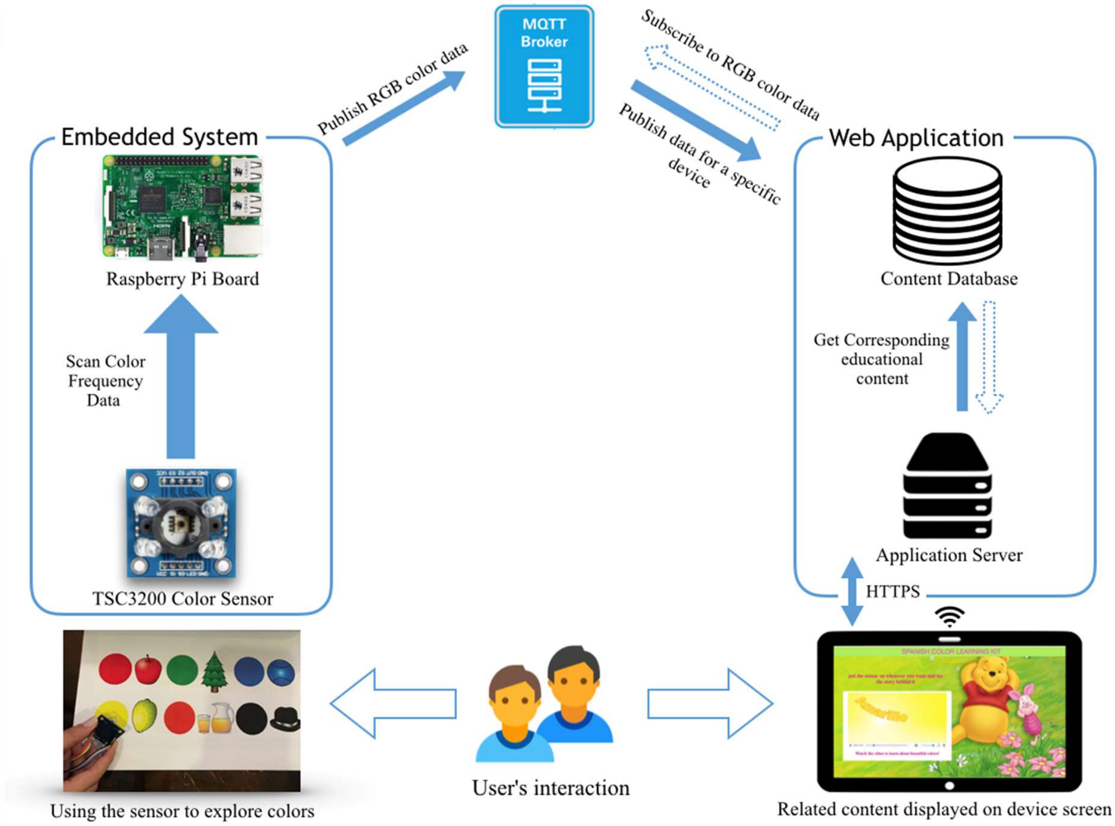

Figure 1. Components of AR-based Color Sensing Proposed System.

In order to make the object recognition feasible, some specific elements such as Qrcode [22] and RFID tags [23] have been used.

The dramatic increase in foreign language learning outcomes of such research studies encourages us to continue exploring the way AR and IoT can be collectively used for teaching vocabularies to younger learners. Regarding this, we have applied color sensors as some means for facilitating the process of teaching color names to children.

III. The Proposed Approach

1. Basic Idea

The major purpose of this research is to find a new way for exploiting abilities of alternative technologies to enriching kids' basic knowledge. Within this context, a basic idea is to take into account sensing the colors of real-world objects as a tangible interface between children and computer, and augmenting the correspondent multimedia content on that. The major goal is to design an e-learning system to deliver multimedia educational content with the ability to run on a wide range of hardware devices and in the meantime simple enough for children's self-study with minimum skills.

2. IoT as the Ground for the Proposed Idea

By allowing human-to-human, human-to-machine and machine-to-machine interaction, IoT gives us a new perspective for designing e-learning tools and systems [24]. Things would be able to recognize their surroundings with sensors and can perform rational actions towards their environments via internet-connected actuators. Regarding this, the following items are required [25]:

a. Hardware, including sensors, actuators and communication devices.

b. Middleware, described as storage and computing systems for analyzing data.

c. Presentation, interpretation and visualization tools for interaction between end users and the system.

Based on these requirements, we have designed a color sensing interactive system for children, which enable them to learn colors in a foreign language (in our case Spanish). In our approach, first, color sensors collect data from the surroundings, then the data is sent over the internet, and on the sever side the data is processed and the corresponding multimedia educational content (Combination of audio, video and text) will be displayed on the user's browser.

According to our approach, users will receive the educational content while they are pointing the color sensor to an object in their surroundings. In our experimental setting, we designed a specific colored book for the children to enable them to point the sensor to different colors on different pages, and face them with an animation that teaches them each color in Spanish language.

Our proposed system consists of three main components: embedded system, machine-to-machine (M2M) communication system, and web-application for user interface. (Figure 1).

As it is seen from the embedded system, Color sensor data signal is processed on a Raspberry Pi board and a RGB color code is then transmitted to the server side program within appropriate time intervals. Communication between the devices and the server is done using the MQTT message passing protocol. Each Raspberry Pi board publishes its own data, and the data is then sent to the MQTT broker responsible for queuing the messages. Server-side program receives messages from the queue while processing each message based on the received color data, and then deciding the proper video content for each user. The proper video is then presented on each user's web browser at the same time that the sensor is pointing to each color.

In this manner, the computational load is reasonably decreased on the client side and embedded device. We may see any internet-connected device (Smartphone, Laptop, and Tablets) can be used as the visual platform for this purpose.

3. *Color Sensing Embedded System*

The cost-efficient TCS3200 color light to frequency converter was selected out of the commercially available color sensors for the color sensing purpose. The processing and communication tasks on the embedded device are done using a "Raspberry Pi Model B +" single-board computer. Two inputs are used as command for choosing measurement between red, green and blue colors. Each of the three light frequencies are sampled 20 times separately for each sensor.

The ambient light can affect the color detection accuracy of the sensor. In order to minimize the adverse effects of the ambient light on the measurement, a calibration phase is performed at the startup of the system. In the calibration phase, black and white color frequencies are measured as the reference for the later measurements. Using equation 1, each color frequency is converted the RGB triplet format.

$$RGB = 255 \times (f_{sampled} - f_{black})/(f_{white} - f_{black}) \quad (1)$$

4. *Machine-to-Machine Communication*

This As mentioned earlier, each device should be able to communicate with the server-side program and transmit the color data in real time. Delays can affect user experience quality and is therefore a crucial factor in the proposed system. To reduce delay, MQTT protocol is employed for the communication between embedded devices and the server. Since RGB color data has a period of 1Hz frequency, data loss would not affect the user experience.

5. *Web Application and Presentation System*

In order to augment the educational content with the multimedia content, a web application, which is accessible by clients from their internet-connected devices, is employed. Considering the age of our experiment audience, a graphical user interface containing instructive notes and colorful elements were implemented on the front-end of this web application. The server-side program subscribes to all message topics and captures the medium. Here, each message (RGB color data) is processed in a first-in-first-out manner. In order to match the RGB colors with the appropriate video file, each RGB color is first mapped onto a pre-defined color name using the procedure presented in algorithm 1. CSS default color names are used as the reference for this purpose. Figure 2, shows the pseudo code of finding the closest CSS color name for a given RGB triplet.

```
Find Closest Color Name for a given RGB triplet

Input: A triplet containing RGB values for the requested color
Output: Name of the color (from CSS colors) that is the closest to the given RGB triplet
minimum difference = 255
FOR each color   in  CSS colors
        squared_diff_red = square (color.red – requested_color [0])
        squared_diff_green = square (color.green – requested_color [1])
        squared_diff_blue = square (color.blue – requested_color [2])
        squarde_difference = squared_diff_red + squared_diff_green + squared_diff_blue
        IF (squarde_difference == 0) then
                return color.name
        IF squarde_difference < minimum_difference then
                minimum_difference = squarde_difference
                result = color.name
Return result
```

Figure 2. The pseudo code of the algorithm for mapping RGB to color names.

IV. Experimental Results

Our purpose is to evaluate the effectiveness of the proposed system on children's vocabulary learning. With this in mind, we designed some experiments to measure the effectiveness of the proposed approach on learning performance usability of the system as well. Experimental results address the technical aspects of our approach and the color measurement accuracy of the system. Besides paired T-test conducted in our previous experiment [26] to evaluate the learning performance, in this research, system usability is also evaluated using System Usability Scale (SUS) questionnaire [27].

1. *Experimental Setup and Procedures*

In this section, the setup and procedures for conducting our experiments to measure learning impact and usability of the proposed system are described. For this purpose, a book containing colorful images of cartoon objects and characters, including common colors with no text, was designed. Each page of this book represents a single scene as a target image for augmenting the corresponding multimedia content in order to provide an immersive experience. The multimedia contents were designed in a way to represent the same colored object in an animated musical manner. The music repeatedly sings the corresponding word for each color.

In our experiment, the colors' names in Spanish Language were considered as new vocabularies to be taught to the students. The reason for choosing this language refers to the point that, in Iran, the popular foreign languages in schools are English and Arabic, and in primary schools, the focus is more on English. Therefore, we thought there might be very few children familiar with Spanish language and our pre-test results confirmed this assumption. In this way, the effect of the system on enhancing the learning performance can better be shown. However, this system can be easily customized to teach any desired language.

According to our instructional strategy, pupils were first guided to use the system paying attention to discovery learning and hands-on learning without any intervention from the teacher side. According to [28], discovery-based instruction can enhance learning, and role of teacher is just to provide examples of how to complete the task and how to interact with the system before starting the procedure. Children interact with the system using the color sensor and a 24-inch LCD display monitor with speakers. Here, any internet-connected device can be usable successfully. The participants are asked to hold the color sensor and explore the book, while watching the display monitor. On different pages of the book (by detecting the color of the images by color sensors), the corresponding multimedia content was augmented on the display screen and the process was repeated by the participant for several pages.

Colors of the objects within the book were scanned by color sensors, to provide a controlled environment for our experiments. In this way, identical colors were used for pre-test and post-test evaluations. In addition, it was feasible to have an immersive experience while making use of corresponding augmented multimedia content that tells the story of the colors in the book pages. To conduct the test, we went to one of the best primary school's classrooms with prior permission. The classroom was primarily used for teaching computer skills. Afterwards, pupils were called one by one for the test. Subjects for test were 70 female pupils, aging from 10 to 12, picked at random. The test started with a simple quiz designed by the authors of the paper: each pupil was shown a page containing the colors Blue, Red, Yellow and Green and was verbally asked if she could say any of these colors in Spanish language. After that, a brief instruction was given by the teachers on how to interact with the system. Afterwards, each pupil was given ten minutes to work with the system and discover the book and colors on her own, while her behavior was being monitored using laboratory observation methods. None of the monitored pupils had difficulties while working with the system. After this session, each participant was asked to take a 10 minutes break and then return to the classroom. The teacher then used the exact same four-color quiz (the participant was asked verbally if she could recall any of the four colors in Spanish) for each pupil. After the second quiz, each participant was asked to fill the System Usability Scale (SUS) questionnaire that is presented in Table 3.

2. *Impact of Learning*

Various theories and methods exist for designing and evaluating learning performance and outcomes [29] based on the learners' learning style model such as Felder-Silverman [30] or cognitive layers of Bloom [31], etc. In this research, we selected Paired T-Test for evaluating learning performance. Such a selection is due to the limited number of test population, limited times allowed for interacting with pupils, and finally the limitations in color sensing AR-based system designed for teaching color names in Spanish Language. To realize evaluation, it is essential to consider the impact of the proposed system on children learning performance. Regarding this, it was necessary to investigate the learning performance of the same test population before and after using the proposed color sensing system [26]. Regarding this, the best choice for evaluating learning performance was decided to be Paired T-Test. However, in case of being able to have more interaction, Felder-Silverman method can be a better choice for modeling the learning style of pupils.

Since the Iranian schools are uni-gender, we decided to concentrate on a girls' school for our evaluation purpose, and the test population selected accordingly, were 70 female pupils, aging from 10 to 12, picked out randomly from the primary school.

By comparing the pre-test and post-test scores, we could determine whether the user's knowledge improvement was statistically significant or not. It is worth noting that the duration of user's learning was an uncontrolled variable in this experiment, although a threshold of 10 minutes considered for each person. The statistical results of comparing pre-test and post-test scores are illustrated in Table 1.

As shown in Table 1, the participants scores increased considerably in post-test; considering mean that has been changed from 0.071 in pre-test to 3.1 in post-test, also the three times mutation of median of the scores is another strong evidence. The standard deviation of the scores shows greater spread in the data in post-test. This makes sense as learner's enthusiasm for learning more colors in Spanish language, and besides that, the learner's unfamiliar-ness with Spanish words.

As mentioned earlier, in order to evaluate the learning performance, we applied paired T-test, whose results are shown in Table 2. The paired T-test revealed that the mean of participant's post-test scores was 3.1, with the standard deviation of 0.819, while the corresponding variables were 0.071 and 0.310 for the pre-test scores. The interpretation of the paired T-test in our experiment is reliable according to the SD values in pre-test and post-test results, and the fact that no major outliers detected. The most striking result is that, the scores increased averagely by 3.029 points after interacting with the system, which means an improvement of 75%. In addition, a P-Value of 2.39E-40 attained, which is less than the significance level (0.05). Meanwhile, a confidence interval of 95% confirms that the impact of the system on the means of participants' score before and after interacting is statistically significant.

TABLE I. STATISTICAL RESULTS ON PRE-TEST AND POST-TEST SCORES.

	Pre-Test Scores					Post-Test Scores				
	Mean	*Median*	*Standard Deviation*	*Min*	*Max*	*Mean*	*Median*	*Standard Deviation*	*Min*	*Max*
Pupils	0.071	0	0.310	0	2	3.1	3	0.819	1	4

TABLE II. STATISTICAL PAIRED T-TEST RESULTS.

T-Test: Paired Two Sample for Means		
	Pre-Test	**Post-Test**
Mean	0.07142857143	3.1
Variance	0.09627329193	0.671014492753623
Observations	70	70
Pearson Correlation	-0.02851031741	
Hypothesized Mean Difference	0	
Df	69	
t Stat	-28.65790334	
P(T<=t) one-tail	2.39122109859309E-40	
t Critical one-tail	1.6672385491545	
P(T<=t) two-tail	4.78244219718618E-40	
t Critical two-tail	1.99494539	

3. *System Usability Evaluation*

As the target audiences in this experiment were children, their interaction with the system was one of the most important factors to be evaluated. In this respect, System Usability Scale (SUS) [27] as well as user experience are important criteria which can be evaluated via the SUS and UEQ questionnaires [32] which seem to be usually very helpful [33]. In this regard, to assess the usability of the proposed system, we made use of System Usability Scale (SUS) questionnaire [27], which is one the most simplest and reliable usability evaluation metric tools that can be used for a wide range of applications [34].

The usability experiment was conducted on the same population whose learning performance was already evaluated by paired T-Test. Children had the chance to use the system independently under the guidance of a teacher. The teacher later asked from each participant 10 items out of the SUS questionnaire where their immediate responses to each item were recorded.

Respondents were asked to select a score ranging from 1 to 5 based on their level of agreement for each item. The score given by each child is summed up, while the average for each item (ranging from 1 to 5) is calculated. (Table 3). It is obvious that odd-numbered questions are in a positive tone, while the even-numbered questions are in negative.

Equation 2 is adapted from [35] and shows how SUS score is calculated. The $\overline{S_i}$ is the average of the respondents' answers (mean raw score) for the i[th] question. Score contribution for each item and total SUS score is calculated and compiled in Table 3.

$$SUS = 2.5 \times \left[\sum_{n=1}^{n=5} (\overline{S_{2n-1}} - 1) + (5 - \overline{S_{2n}})\right] \quad (2)$$

In Table 3, comparing each question's score contribution, can possibly illustrate weaknesses and strengths of the system. For instance, the fourth question is rated worse than the rest; this could mean that children need support of a teacher to use the system for the first time. It seems likely that we can improve the user experience of the proposed system by adding interactive instructions on how to use the device for the first time. Overall, Lewis and Sauro [36] had shown that "learnability" assessment could be done separately by score contribution of the 4th and 10th question.

The test results offered a total score of (mean 78.39, SD 16.57) which is considered above average of SUS scores reported in the previous usability studies (69.5) [37]. Thus, the system can be considered acceptable by the experiment population who were exposed to our system for the first time.

In order to translate the numeric scores to an absolute judgment, an overall adjective equivalent for each score were employed in several studies. By using the same adjective rating, the achieved SUS value in our experiment (78.39) can be mapped to the adjective "Good" as an overall evaluation for usability of the proposed system. Figure 3 shows frequency distribution of SUS results. Under each histogram bar, corresponding adjective rating for each interval is also showed in order to make the score intervals more sensible. The presented histogram illustrates that 85.72% of the SUS scores were above 60. Therefore, it may be assumed that 85.72% of the test populations were satisfied with the usability of the system.

TABLE III. SYSTEM USABILITY SCALE QUESTIONNAIRE AND RESULT SUMMERY.

Questions	Mean Raw score (from 1 to 5) (1) Strongly Disagree / (2) Disagree / (3) Neutral / (4) Agree / (5) Strongly Agree	Item Score Contribution (from 0 to 4)
1. I Think that I Would Like to Use This System Frequently.	4.11	4.11 -1 = **3.11**
2. Found the System Unnecessarily Complex.	1.71	5 - 1.71 = **3.29**
3. I Thought the System Was Easy to Use.	4.06	4.06 – 1 = **3.06**
4. I Think That I Would Need the Support of a Teacher to Be Able to Use This System.	2.90	5 – 2.90 = **2.10**
5. I Found the Various Functions in This System Were Well Integrated.	3.77	3.77 – 1 = **2.77**
6. I Thought There Was Too Much Inconsistency in This System.	1.20	5 – 1.20 = **3.80**
7. I Would Imagine that Most People Would Learn to Use This System Very Quickly.	4.66	4.66 – 1 = **3.66**
8. I Found the System Very Cumbersome to Use.	1.43	5 - 1.43 = **3.57**
9. I Felt Very Confident Using the System.	4.34	4.34 – 1 = **3.34**
10. I Needed to Learn a Lot of Things Before I Could Get Going with This System.	2.34	5 – 2.34 = **2.66**
Sum of Item Scores Contribution		31.36
Overall SU Value (Sum * 2.5)		78.393

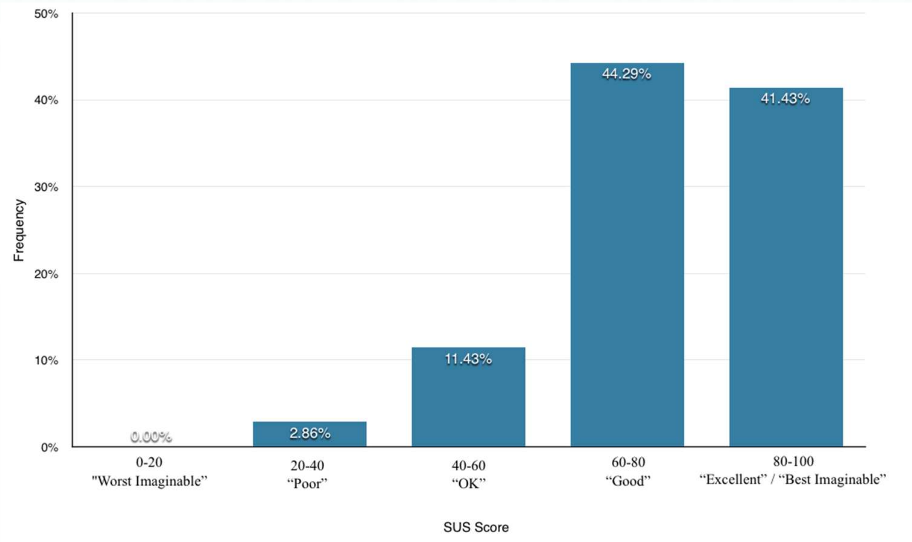

Figure 3. Frequency distribution graph of SUS scores and correlated adjectives.

4. *Accuracy of Color Measurement*

It is likely that the obtained results have been influenced by a number of limitations. The color sensor is not always accurate in translating the colors into their RGB equivalent. To mitigate the effect of this error, an accepting area has been considered for each color according to its exact RGB equivalent and any number in this domain would be accepted as the corresponding color. For the system to be utilizable in every light condition, we calculated the average measurement error under various circumstances.

To do this, we decided to conduct an experiment for examining the accuracy of red, green and blue values in measurements. First, five points that equally divided the 0 to 255 range were selected (0, 63, 127, 190, 255).

Secondly, we scanned the colors that these values represented in both day light and artificial light. As the result, the color real values' dispersion in comparison to the expected values is shown in Figure 4.

Since we are using the measured colors for choosing the proper content to show to the users, we need a more tangible analysis for measurement from the aspect of human visual perception. Accordingly, we employed "Delta E" which is a metric based on three-dimensional CIELAB color space. The L* indicates the lightness and a* and b* values are dedicated to red, green, blue and yellow colors. This metric typically used to evaluate the visible difference between two colors in human eye perception. Table 4 demonstrates the Delta E calculated for 10 sample RGB color points that were measured using our system. The value for Delta E difference is a number ranging from 0 to 100. The value between 0 and 1 means that the difference between two colors is not perceptible by human eye while the 100 value means that the two colors are exact opposite. Our result shows a mean Delta E value of 16.669, which indicates that the measured colors are similar to the true colors but the difference, would be recognizable by the human eye. The Delta E values for the true color and measured color is presented in Table 4.

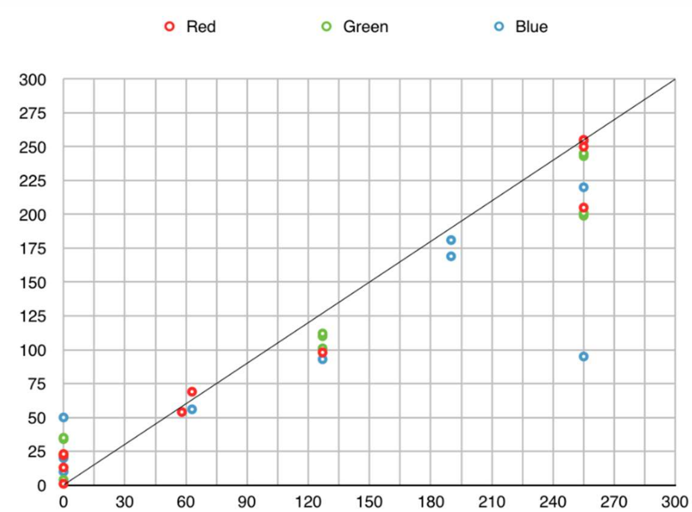

Figure 4. Colors' real values dispersion relative to y = x line

TABLE IV. DELTA E VALUES FOR COLOR PERCEPTION EVALUATION.

Genuine RGB Values			Average of Measured Values			ΔE
R	G	B	R	G	B	
0	0	0	1	4	10	2.756
255	0	0	205	35	50	36.023
0	255	0	23	199	20	29.031
0	0	255	22	34	95	36.4
127	127	127	98	101	93	11.98
255	255	255	255	243	254	7.65
63	255	255	69	201	220	23.67
0	127	63	13	112	56	7.88
255	127	190	250	110	169	7.80
58	255	190	54	245	181	3.50
Average ΔE						16.669

V. CONCLUSION AND FUTURE PROSPECTS

Assuming the empirical interest in interactive learning and by exploiting the possibilities of IoT in education, this work has focused on a novel approach targeting younger audience and with the goal to enrich their basic knowledge; an AR-based interactive learning system was successfully designed, implemented and evaluated. Although the proposed approach has been implemented to support learning of colors as vocabularies, it can however be equally applied to support learning of any kind of object that can be sensed (through using sensors) in reality.

The experimental results would seem to show that the proposed system could be practically used by children for vocabulary learning and gaining knowledge. The mean score of the experiment population were improved by 75% and the paired T-test results, highlighted a significant improvement in test scores of children after interacting with our system in a self-instructional manner.

Our work indicates how a low-cost color sensor, can be practically used as an interface between children and computer for making an interactive learning system.

Admittedly, it is not possible to totally avoid uncertainty and error in sensing the colors of real world objects due to hardware limitations. The error in color measurement is mainly caused by the delay in the counter GPIO pin and accuracy of the Raspberry Pi clock frequency. In addition, the employed sensor has the output 0.2% nonlinearity error at 50 KHz. We have presented some procedures to minimize the hardware limitation and adverse effects of ambient light. In order to evaluate the color sensing accuracy of the system, the “Delta E” metric was employed for a better understanding of how these errors are perceived by human eye. The average Delta E for the measured RGB colors is 16.669, which indicates that measured colors are similar to the real colors but human eye can distinguish between our measured color and the real color of the object.

As mentioned in the third section, we categorized the colors and mapped each educational video to a single category of color. The achieved color sensing accuracy shows that the presented system is not capable of differentiating colors that are very similar with (Delta E values less than 30). This limit the number of color categories our system can detect and therefore it limits the number of color codes that can be used for selecting different educational content.

Further examinations were also conducted to measure the usability of the system by children and the feasibility of the interaction. Users’ response to the System Usability questionnaire were analyzed and demonstrated acceptable, above average results and 85% of test population rated overall usability of the system as “good” and “excellent”.

One limitation of our research is that the experiments were conducted on uni-gender (only female) pupils. As the learning styles and preferences of children [38], also their interaction with multimedia resources [39] based on their gender might be different, for future work it is essential to consider and investigate the gender differentiations, too.

The obtained results are encouraging; however, they need to be validated by a larger sample size. In addition, it is important to compare the enhancing effects of the proposed system to the conventional teaching methods for future research. It is suggested to employ T-test and perform an experiment on two group of individuals with one group using the traditional methods and another group using the proposed system. We believe there are some key advantages to this method that cannot easily be achieved with traditional approaches. Using the developed system, a different learning experience was provided to the pupils and our results confirm that, this method can be practical for the educational purposes. Particularly, discovery based learning and providing instant feedback without the teacher’s intervention was significantly feasible using this developed technology.

Although we observed significant improvement in test scores, a closer inspection might be needed considering the functionality of human memory to confirm the effectiveness of the system. Some important factors in this regard are the number of test questions, duration of interaction, and length of recall period.

In the presented approach, children can interact with a smart device and explore their surrounding in a tangible way instead of reading the content and communicating with instructors. Therefore, we believe that our work could possibly be effective for children with learning difficulties such as autism spectrum disorder and dyslexia. Further experiments are needed to validate the usefulness of the system for children with special needs.

The prospect of being able to make the system more interactive serves as an impulse for future research. Exploiting the possibilities of the cloud-based system would lead to add interactive quizzes. Moreover, the IoT technology would enable the researchers to makes a collaborative learning system based on our proposed approach.

At last, with a focus on the color measurement accuracy, future wok would help us to use the colors as unique codes that each of them can be mapped to a multimedia content in order to teach a variety of material using this system.

Although the current paper discusses a color-sensing approach for supporting vocabulary learning in children, its core idea can however be applicable to any domain wherein sensing a sort of physical quality can be finally associated with learning some simple "concepts", "principles" or "procedures", which are beneficial in understanding the surrounding events as well as performing the necessary tasks. Examples can be mentioned for sensing delicate objects, which can be finally associated with learning the concept of avoidance in approaching a dangerous area, which is quite helpful for safety purposes, or sensing unfavorable smells which can be associated with learning the possible sources of these smells. Elaborating these aspects can thus e mentioned as a part of future research work for AR-based evaluation of learning performance and usability in human being in general.

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