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Intravenous drug administration application for pediatric patients via augmented reality

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ABSTRACT

This research presents the development of the intravenous drug administration application for pediatric patients using augmented reality (AR) technology, with a primary focus on aiding nursing students in administering medications accurately to reduce the risk of errors. The system architecture encompasses two core components: the creation of medication preparation videos and detailed drug information, and the design of a mobile application featuring medication list display, drug dosage calculation, user satisfaction assessment, and intravenous drug information addition. The system classifies users into administrators and nursing students, allowing administrators to manage user information in the member database. the application seamlessly integrates Visual Studio Code, flutter, dart programming language, firebase database, and AR.js Studio for QR code-linked videos. Operating in four main parts, namely users, mobile application, member database, and results display, the IDA application enables users to log in, access detailed drug information, calculate dosages, and view AR-based medication preparation videos. Tested with 111 nursing students, the system demonstrated functionality, completeness, and accuracy. The Likert scale-based evaluation revealed high satisfaction levels in content, design, functionality, and benefits received, affirming the intravenous drug administration application's effectiveness in pediatric intravenous drug management through AR, offering an innovative solution for nursing education and error reduction.

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1. INTRODUCTION

The World Health Organization (WHO) has defined patient safety as a fundamental principle of the healthcare system. In recent years, patients have come to expect high quality and safety standards when they seek care in hospitals. Both international and Thai healthcare organizations have adopted patient safety goals as a key priority to ensure patient safety and reduce risks. These goals are also important quality indicators for healthcare facilities. Therefore, safety is the foundation of nursing standards that are aligned with the healthcare system of 2024-2027 [1]–[4]. The policy on patient and personnel safety (2P Safety) is an important policy for creating a sustainable, balanced, and system-based healthcare system with the participation and creativity of all stakeholders. It plays an important role in supporting a sustainable universal healthcare system [5]–[7]. In previous research, observations of medication management errors among

nursing students from January 1999 to December 2003, totaling 1,305 incidents, were categorized by severity according to the National Coordinating Council for Medication Error Reporting and Prevention Index. The findings revealed that errors at severity level C accounted for 70.57% (occurred but not harmful to patients even if the error reached them), and at severity level D, the percentage was 23.29% (occurred without harm to patients but required additional monitoring). Types of medication management errors by nursing students included incomplete administration, incorrect dosage, incorrect timing, administering more than prescribed, administering to the wrong person, administering unprescribed medication, administering via the wrong route, using incorrect preparation techniques, and administering the wrong form, with the highest errors associated with antibiotics, insulin, opioid analgesics, and cardiovascular drugs [8]–[12].

Further research conducted by Triantafyllou *et al.* [13] investigated medication management among nursing students during clinical practice and simulation scenarios. The study found that nearly half of nursing students experienced medication management errors, with the top three errors being wrong dose form, omission error, and wrong time. The study also revealed that nursing students perceived the safety environment in clinical settings as moderate, and most errors occurred during simulation scenarios, with the top three errors being administering to the wrong person, incorrect dosage, and administering medication to a patient with a known allergy [14]. Research by Mendes *et al.* [14], which examined errors in medication preparation and administration, a cross-sectional study and a descriptive analysis were conducted with data collected from the emergency department of a university hospital in Sao Paulo. The sample group included 303 participants, consisting of nursing assistants (60.0%), technical nurses (32.6%), and professional nurses (7.2%). The study found that the most commonly used medications in the emergency department were antimicrobials (24.7%), non-opioid analgesics (23.1%), anti-inflammatory agents (10.5%), anti-emetics (9.5%), opioid analgesics (8.9%), antacids (5.6%), antiarrhythmic agents (3.6%), diuretics (3.3%), anticonvulsants (2.9%), vasodilators (1.6%), antispasmodic agents (1.3%), cardiotonic agents (0.9%), splenic vasoconstrictors (0.6%), antidiabetics (0.6%), vasopressors (0.6%), vitamins (0.3%), and bone catabolism inhibitors (0.3%). All types of medications used were not expired. The study found errors in the medication preparation process, including lack of hand hygiene before medication preparation (70.2%), failure to use aseptic techniques (80.8%), incorrect labeling of medications (47.9%), failure to verify patient identity (62.3%), and diluting medications in quantities less than recommended by the manufacturer (1.6%). In terms of medication administration, the study found that administering more than one type of medication simultaneously resulted in medication incompatibility in 56.8% of cases. Errors in the medication preparation and administration processes may have serious consequences for patients, including disability, prolonged hospital stays, and even death. The occurrence of or medication errors that are often found in newly graduated nurses or practical nursing students is that most of them lack medication administration skills, especially intravenous medication administration, such as calculating the dose, mixing the correct drug into the solution, evaluating side effects, and providing appropriate nursing care to the patient after receiving the drug [15]–[18]. Although nursing students have learned the theoretical knowledge of drugs in the pharmacology course and have undergone practical training in the basic nursing course, they may lack experience in providing nursing care for children. This can lead to misunderstanding and the inability to apply knowledge to intravenous drug administration in children in real-world situations.

Currently, internet technology can be connected through smartphones. If an application is developed, it can be used to research and support patient care conveniently in drug administration that can be viewed at any time. The pervasive integration of mobile devices into healthcare practices is driven by the growing availability and quality of medical software applications, commonly known as "apps." These apps, designed for both computers and mobile devices, capitalize on technological advancements such as faster processors, improved memory, and efficient open-source operating systems [19], [20]. Healthcare professionals benefit from the ability to download medical apps, gaining access to a plethora of clinical resources that cover electronic prescribing, diagnosis, treatment, practice management, coding, billing, and continuing medical education (CME) [21]–[23]. The diverse array of apps caters to various needs, including drug references, medical calculators, clinical guidelines, literature searches, and simulations of surgical procedures or medical exams. While not intended to replace desktop applications, these medical apps aim to complement them, enhancing resource availability at the point of care. In parallel, drug reference applications are extensively utilized to retrieve comprehensive information encompassing drug names, indications, dosages, pharmacology, interactions, contraindications, cost, formulary status, identification guides, and dose-by-weight calculators. Noteworthy mobile drug reference apps, such as Epocrates, Skyscape RxDrugs/Omnio, Micromedex, Food and Drug Administration (FDA) Drugs, and DrugDoses.net, play a pivotal role, allowing simultaneous checking of multiple drug interactions. The observation that 90% of physicians, especially users of the widely adopted Epocrates app, turn to mobile applications for crucial drug information underscores the prevalence of their use. Moreover, the integral role of mobile devices in medical education is increasingly prominent, with students and institutions leveraging technology for diverse purposes during training. Health care students utilize mobile devices as versatile tools for logging experiences, accessing information on medical conditions and drug treatments, performing calculations, and making quick notes. These devices have become omnipresent in

educational settings, serving as "learn anywhere" resources for information retrieval and knowledge verification. Mobile apps designed for health care students facilitate knowledge assessment through case study quizzes and board examination preparation, demonstrating enhanced learning outcomes. Furthermore, international associations, such as the American Association of Colleges of Nursing, advocate for the use of smartphones in nursing practices to enhance clinical skills related to patient care technologies, information systems, and communication devices, fostering safe nursing practices. Entry-level nurses are expected to possess technological proficiency, including the use of nursing-specific software like computerized documentation. The United States National Library of Medicine supports nurses through programs like PubMed on Tap, enabling access to up-to-date research and clinical information directly at the bedside. Smartphones prove instrumental in nursing care by facilitating enhanced interprofessional communication, improved information access at the point of care, efficient time management, and stress relief. Healthcare professionals, particularly nurses, utilize smartphones across various domains, emphasizing their pivotal role in guiding clients and patients towards tools that enhance health, wellness, and disease management.

This research has developed an innovative intravenous drug administration application for common pediatric patients. The project comprises two components: i) the creation of medication preparation videos and drug details for ten different pediatric drugs and ii) the development of a mobile application and user interface using Visual Studio Code and programmed in dart language. The application covers information about drugs (drug class, mechanism of action, side effects, drug interactions, and nursing care for patients receiving drugs), drug calculation, and drug preparation through augmented reality (AR) technology that displays video results (selection of the appropriate type and amount of solution and proper drug administration). It is expected to be beneficial for developing intravenous drug administration skills in pediatric patients of nursing students or new nurses.

2. METHOD

2.1. System overview architecture

The intravenous drug administration application for pediatric patients through AR technology is an application developed to support users by allowing them to view drug information and drug preparation through AR technology, helping to administer drug correctly reduces the risk of drug misuse. From analyzing the main functions of the intravenous drug administration application for pediatric patients through AR technology that shows the main activities of the entire system architecture as shown in Figure 1. The intravenous drug administration application has been copyright registered in Thailand Department of Intellectual Property (DiP), Copyright No. W1.010878.

The system overview classifies users into two types: system administrators and users (nursing students). Users need to login to the system before being able to view detailed drug information, calculate the doses of intravenous drugs, and display medication management outcomes using AR technology. Administrators (admin) can access the application to update the system, maintain and repair it for improved stability. The admin, responsible for user database management, can access the member database on the system's intravenous drug administration application. System administrators can perform three commands: i) adding user information and user status, with the added information being recorded in the member database; ii) editing user information; admin can access and modify user information and user status recorded in the member database; and iii) deleting information; admin can use the delete user command to remove unwanted user data from the member database. After each command is executed, the status is updated and reflected on the member database management page in the application.

Figure 1 illustrates the system overview diagram for the intravenous drug administration application for pediatric patients using AR technology. The application is developed using Visual Studio Code connected to Flutter, utilizing the dart programming language. The user interface design for each page is created to connect with the Firebase database. Regarding AR technology, the developers use AR.js Studio to create QR codes linking to videos demonstrating drug preparation and drug images [24]–[26]. The URLs generated from the QR codes are stored in the database to be linked to Visual Studio Code for display in video format. The intravenous drug administration application for pediatric patients operates in four main parts: i) users, ii) mobile application, iii) member database and intravenous drug information, and iv) results display page through the intravenous drug administration application for pediatric patients. Users start by logging in, where the system checks the correctness of the username and password in the member data database, which was registered previously. After successful login, users can access the intravenous drug administration application for pediatric patients, which features a list of drugs and information about intravenous drugs for pediatric patients. When a user selects a specific drug, the system sends the stored drug data from the database, and the information is displayed using AR technology in the intravenous drug administration application for pediatric patients. Additionally, the intravenous drug administration application can calculate the dosage of intravenous drugs for pediatric patients. Users input data such as drug doses, weight, and the number of times the drug is administered per day. The intravenous drug

administration application for pediatric patients then calculates the dosage for each administration, considering physician treatment instructions, to provide a suitable drug doses and reduce errors in medication management. The results are displayed as a numerical bar on the smartphone for easy monitoring.

2.2. System description

The description of the system in Figure 2 will illustrate the main interface of the intravenous drug administration application for pediatric patients through AR technology. When users enter personal information, including username, occupation, email, and password, for registration and storage in the member database, they can access the intravenous drug administration application's home page. This page consists of four menus: i) drug list menu: users can click to view details of intravenous drugs. The application allows users to choose the desired method of medication management in the form of instructional videos or AR-based instructional videos. ii) drug dose calculation menu for pediatric patients: users must enter drug doses, weight, and the number of times the drug is administered per day for pediatric patients. The application calculates the dosage for each administration, and the results are displayed as a numerical bar through the intravenous drug administration application on smartphones. iii) user satisfaction assessment menu: the intravenous drug administration application allows users to assess their satisfaction with the application usage. This feedback helps in making improvements to the intravenous drug administration application in the future. iv) add intravenous drug information menu for pediatric patients: users can input information, including drug name, drug group, trade name, format/strength, pediatric dosage, mechanism of action, pharmacokinetics, indications, and side effects/adverse reactions. The information gathered through these menus is stored in the member database for further reference and utilization within the intravenous drug administration application.

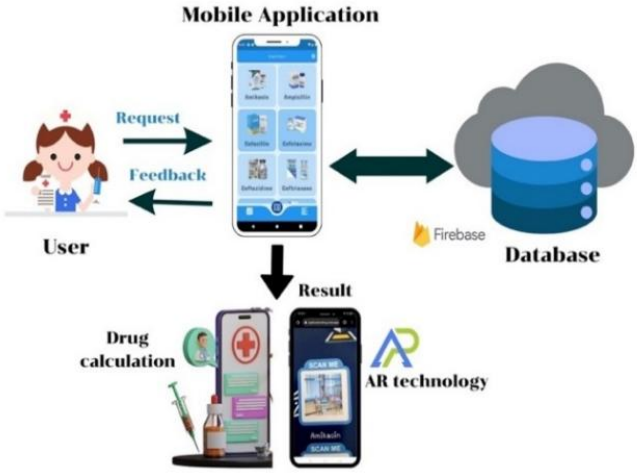


Figure 1. System overview architecture for the intravenous drug administration application for pediatric patients

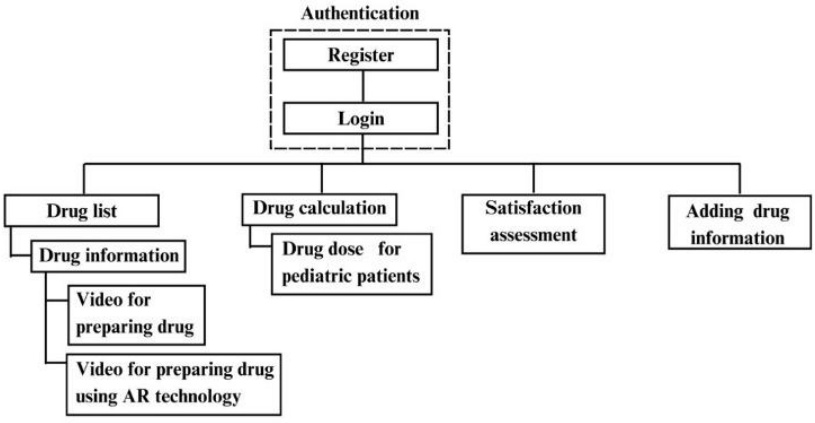
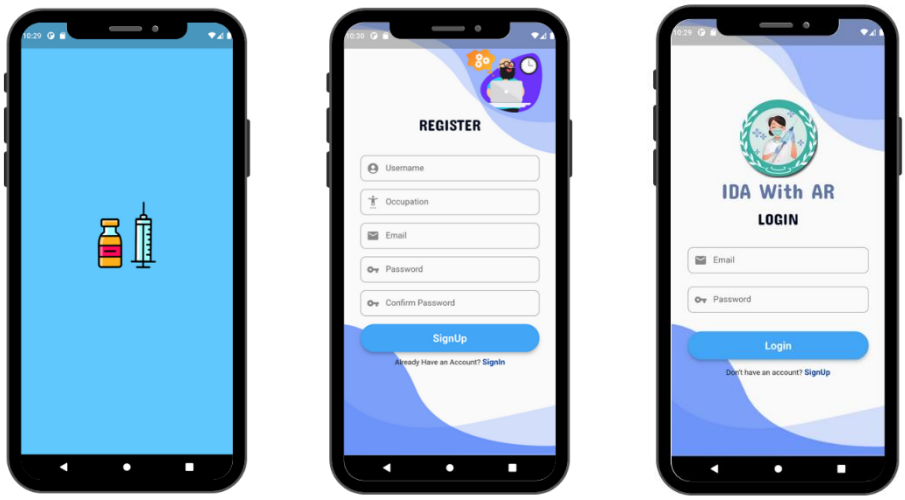


Figure 2. Summary of the functions of the system

3. RESULTS AND DISCUSSION

3.1. Authentication by logging

Authentication by logging for intravenous drug administration for pediatric patients via AR technology as shown in Figure 3. The home page of the application is shown in Figure 3(a). Login authentication requires users to register and provide their personal details which include username, occupation, email, password, and confirm password. After registering, press the SignUp button as shown in Figure 3(b) to confirm your user identity by filling in user's email and password. To log in, use your existing credentials and press the login button as shown in Figure 3(c).



(a) (b) (c)

Figure 3. Authentication by logging into (a) home page of the application, (b) register page, and (c) login page

3.2. Drug list

The intravenous drug list for pediatric patients gives 10 examples: amikacin, ampicillin, ceftriaxone, meropenem, vancomycin, ceftazidime, cefotaxime, cefazolin, cloxacillin, and gentamicin. Users can select intravenous drug for pediatric patients to view detailed information as illustrated in Figure 4. The application displays detailed drug information and has two menus in the upper right corner: show a video teaching material on intravenous drug administration for pediatric patients using AR technology and show a video of intravenous drug administration teaching materials as illustrated in Figure 5. The video page for preparing intravenous drug for pediatric patients can be viewed in two formats: a video and a video using AR technology and image scanning as shown in Figures 6(a) to 6(c).

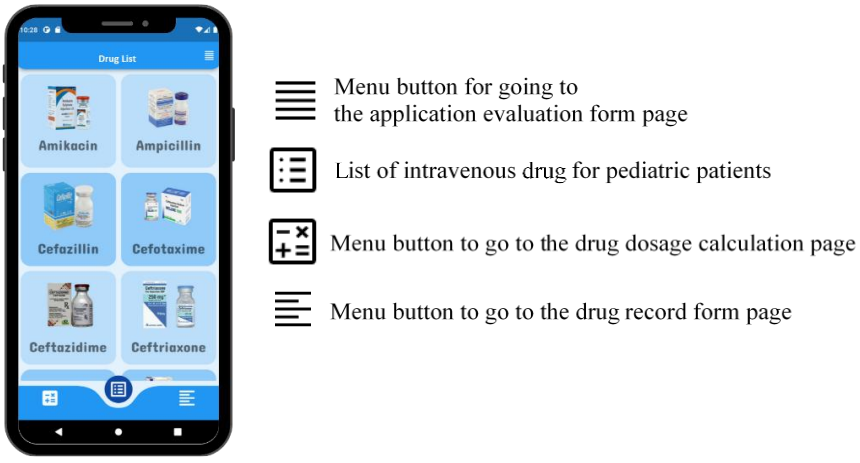


Figure 4. Intravenous drug list page for pediatric patients

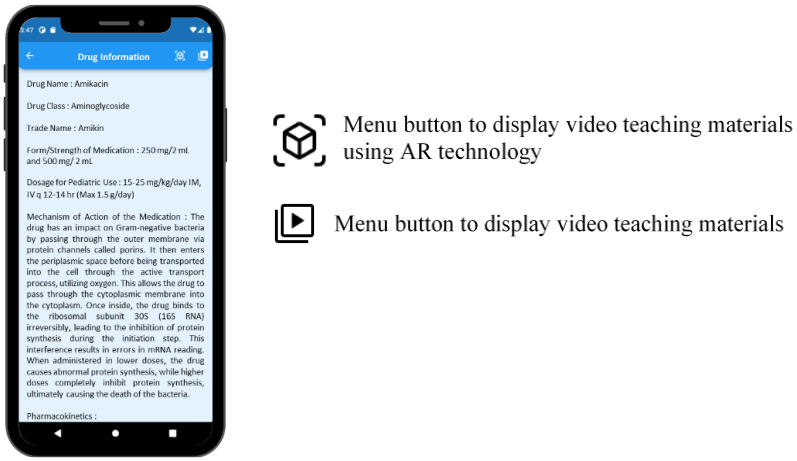
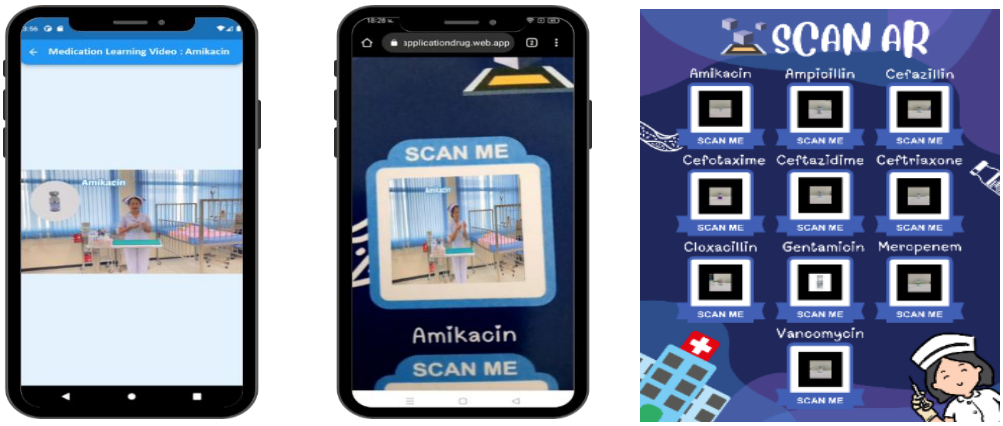


Figure 5. Drug information page



(a) (b) (c)

Figure 6. Video page for preparing intravenous drug for pediatric patients (a) video of drug preparation, (b) video of drug preparation using AR technology, and (c) image for scanning AR

3.3. Development of drug dosage calculations

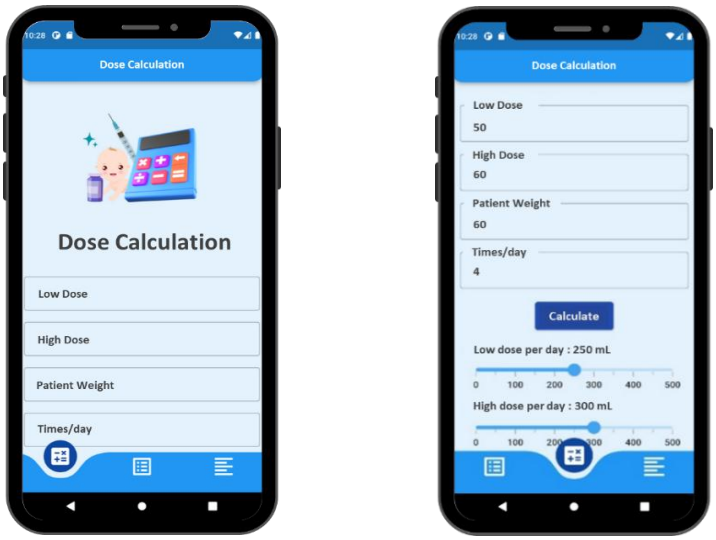
The intravenous drug administration application page for calculating intravenous drug dosages for pediatric patients as shown in Figure 7. User input the following information: low dose, high dose, prediatric patient weight, and number of times per day in Figure 7(a). Figure 7(b) illustrated dose calculation example, the calculation displayed dose results for low and high doses administered once per day in the application.

3.4. Application satisfaction assessment

Application satisfaction assessment is the process of collecting and analyzing feedback from users about their satisfaction with an application. This feedback can be used to improve the user experience, identify areas for improvement, and make decisions about future development. Application satisfaction evaluation form page it allows users to evaluate their satisfaction in using each aspect, consisting of i) basic information about the evaluator, ii) application design, and iii) benefits received, as shown in Figure 8.

3.5. Adding intravenous drug information to the system

The developed intravenous drug administration application allows users to add information about intravenous drugs through a form as shown in Figure 9. The form for adding drug information includes the following fields: drug name, drug class, trade name, drug form, dosage used in pediatric patients, mechanism of drug action, pharmacokinetics, indications for use, and side effects or adverse reactions. The information gathered through these menus is stored in the member database for further reference within the application.



(a) (b)

Figure 7. Intravenous drug administration application page for calculating intravenous drug dosages for pediatric patients (a) dose calculation page and (b) dose results for low and high doses administered once per day

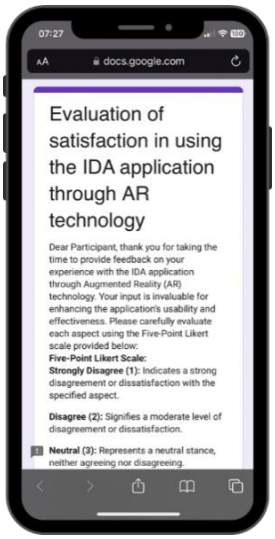


Figure 8. Application satisfaction evaluation page

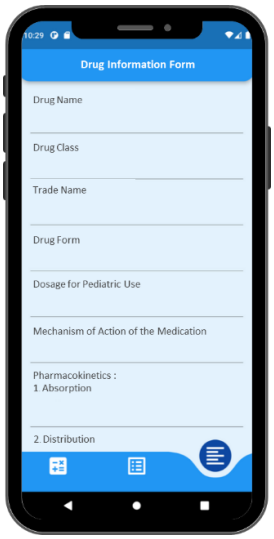


Figure 9. Form page for adding intravenous drug information

3.6. Intravenous drug administration application testing

To verify the completeness and accuracy of the intravenous drug administration application for pediatric patients using AR technology according to the system requirements, three testing steps are required: i) an example of a target group for testing the developed application is N=111 nursing students, Thailand; ii) to log in to the intravenous drug administration application, users must first download the application to their mobile phone, apply for membership, and confirm their application. Once the application is accessed, users must log in with their correct information. If the information is incorrect, the system will notify the user of the error; iii) upon entering the home page of the intravenous drug administration application, users will see a list of 10 drugs to choose from: amikacin, ampicillin, ceftriaxone, meropenem, vancomycin, ceftazidime, cefotaxime, cefazolin, cloxacillin and gentamicin. Users can press on a drug to view its details, calculate the amount of drug needed, or view the process of administering the drug through AR technology. The results of the evaluation of satisfaction in using the intravenous drug administration application are shown in Table 1. The evaluation of satisfaction in using the intravenous drug administration application

through AR technology with a total of 111 respondents, as measured by a five-point Likert scale, reveals a high level of content satisfaction among users. Participants rated the clarity, accuracy, and trustworthiness of the content at an impressive mean of 4.62 with a standard deviation of 0.79. Additionally, the modernity and practical utility of the content received an equally high mean of 4.62, with a slightly higher standard deviation of 0.88. The arrangement and categorization of content also earned positive feedback, with means of 4.29 and 4.36, respectively. Moving to the design aspect, presentation elements like appropriateness, ease of understanding, synchronization with images and sounds, and appropriate duration all scored above 4, demonstrating a favorable user perception. The utilization of images and videos within the application garnered positive responses, with means ranging from 4.32 to 4.42, indicating that users find them appropriately enhancing the content. Sound and language components were well-received, with clear and pleasing sound, appropriate language, and suitable sound effects and music, all scoring above 4. Furthermore, font style, size, and color were deemed complementary and effective by users, with a mean of 4.35 and a standard deviation of 0.83. The functionality of the application, crucial for user satisfaction, received high marks across various dimensions. Application requirements were met with a mean of 4.62, while functions working correctly, convenient use of commands, and fast processing all scored above 4, reflecting users' positive experiences with the application's performance. In terms of benefits received, the intravenous drug administration application demonstrated its effectiveness in promoting knowledge and understanding of intravenous drug administration (mean 4.39), being beneficial for intravenous drug administration (mean 4.39), and eliciting a willingness among users to continue using the application's services in the future (mean 4.25). The application's suitability for dissemination or actual use also received positive feedback, with a mean of 4.34. The overall satisfaction means of 4.42 underscores the success of the intravenous drug administration application through AR technology in meeting user expectations and delivering a comprehensive and satisfactory user experience. In summary, the statistical analysis of the Likert scale responses indicates that users are highly satisfied with the intravenous drug administration application, particularly in terms of content, design, functionality, and the benefits received. The positive feedback across multiple dimensions suggests that the application effectively meets user expectations and contributes positively to intravenous drug administration.

Table 1. Mean and standard deviation of responses to a five-point likert scale of the evaluation of satisfaction in using the intravenous drug administration application through AR technology

Topic	Mean±SD
1. Content	
1.1 The content is clear, accurate, and trustworthy.	4.62±0.79
1.2 The content is modern and can be used in practice.	4.62±0.88
1.3 Arranging content in order makes it easy to read and understand.	4.29±0.87
1.4 Categorizing content makes it easy to find information.	4.36±0.95
2. Design	
2.1 Presentation design	
2.1.1 The presentation is appropriate and easy to understand.	4.33±1.02
2.1.2 The content is in sync with the images and sounds.	4.41±0.69
2.1.3 The presentation techniques are appropriate and realistic.	4.23±0.87
2.1.4 The duration is appropriate.	4.36±0.98
2.2 Images and videos	
2.2.1 Images and videos are used appropriately to enhance the content.	4.42±1.09
2.2.2 Use clear and high-quality images and videos that enhance the content.	4.37±0.96
2.2.3 The content has an appropriate sequence of images and videos.	4.32±0.84
2.3 Sounds and languages	
2.3.1 The sound is clear and pleasing, with an appropriate volume.	4.35±0.75
2.3.2 The language used is appropriate and easy to understand.	4.39±0.96
2.3.3 The sound effects and music are appropriate for the mood or tone of the content.	4.35±0.84
2.3.4 The font style, size, and color are all complementary and work well together.	4.35±0.83
2.4 Functionality	
2.4.1 Meets the requirements of the application users	4.62±1.05
2.4.2 Functions work correctly and completely.	4.37±0.87
2.4.3 Convenient use of application commands.	4.33±0.79
2.4.4 Fast processing by the application.	4.27±0.98
3. Benefits Received	
3.1 Promotes knowledge and understanding of intravenous drug administration.	4.39±0.87
3.2 Beneficial for the intravenous drug administration.	4.39±1.01
3.3 Willingness to use the application's services in the near future.	4.25±0.89
3.4 Suitable for dissemination or actual use.	4.34±0.96
3.5 Overall satisfaction.	4.42±0.87

4. CONCLUSION

The objective of this research is to study the nursing students through the development of innovative intravenous drug administration application for common pediatric patients, aimed at enabling students to administer medications accurately, thereby reducing medication errors. The project comprises two components: ii) the creation of medication preparation videos and drug details for ten different drugs, namely amikacin, ampicillin, ceftriaxone, meropenem, vancomycin, ceftazidime, cefotaxime, cefazolin, cloxacillin, and gentamicin, with the additional step of generating QR codes from drug images. Subsequently, these videos and QR codes are used to produce AR medication preparation videos using AR.js studio. The second part involves the development of a mobile application based on the designed user interface using Visual Studio Code and programmed in Dart language. This application allows users to display a list of medications, calculate drug dosages, add medication information, and connect with the AR medication preparation videos through a URL from the first part. The Firebase platform is employed for data storage. The developed application for managing intravenous medications for pediatric patients through AR seamlessly integrates with the real world, meeting system requirements and user-defined specifications. Overall, the application successfully retrieves medication data from the database, calculates dosages, and displays medication preparation videos through AR technology. The statistical analysis of the five-point Likert scale responses to the evaluation of satisfaction in using the intravenous drug administration application through AR technology demonstrates that content, design, and user benefits, reveals high satisfaction among nursing students regarding the application's usability.

5. RECOMMENDATIONS FOR FUTURE RESEARCH

Future research should adopt an experimental design to rigorously compare the effectiveness of learning outcomes between the Intravenous drug administration application and conventional instructional methods in pediatric medication administration. In addition, Nursing Faculty in educational institutions can integrate the intravenous drug administration application as a supplementary teaching tool to enhance nursing students' learning outcomes in pediatric medication administration.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Siriwan Kajornkasirat		✓			✓				✓	✓				
Jaruphat Wongpanich		✓	✓		✓	✓			✓	✓	✓			
Chulalak Kaewsuk	✓	✓		✓	✓	✓		✓	✓	✓	✓			
Simaporn Puangsuwan	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

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