Comparison of Google Lens recognition performance with other plant recognition systems

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Abstract. In the context of the STEM approach to education, motivating pupils through tailored research and leveraging IT in the classroom is relevant. The justification of these approaches hasn't received much examination, though. The purpose of the study is to support the decision to use an AR-plant recognition application to give tailored instruction throughout both extracurricular activities and the school day. Every phase of an app's interaction with a user was examined and used to categorize every app. Also described were the social settings of the applications and how they were used for extracurricular activities. There has been discussion on the didactics of using AR recognition apps in biology classes. A survey of experts in digital education regarding the ease of installation, the friendliness of the interface, and the accuracy of image processing was conducted to give usability analysis. Applications were examined for their ability to accurately identify plants on the "Dneprovskiy district of Kiev" list in order to assess the rationale of usage. It has been established that Google Lens is the best option. As an alternative to Seek or Flora Incognita, according to the analysis's findings, these apps were less accurate. [1]

Keywords: mobile application, STEM classes, augmented reality, plant identification, Google Lens

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1. Introduction

To date, the introduction of a mobile phone into the educational process is a modern instrument, which provides achieving better results. The usage of a mobile phone during classes provides visualization of educational material, involving students in research, which increases students' motivation for learning [18, 21]. Mobile phone applications compared to computer approaches are characterized by the most promising advantages including mobility of usage, possibility to use both internal and external sensors (not commonly used). The modern educational directions include personalization and research process which may be achieved by using mobile phones. However, it was proved that not certain elements of education but a general didactic approach led to significant effect [33]. The main concept during which the mobile approach relevant to use is STEM/STEAM/STREAM technology. Those methods include using of both, research (scientific) and engineering methods. To improve the efficiency of them, use of computer software or mobile applications can be used.

The role of information technology in the learning process is widely described [7–9, 16, 18, 22, 25, 31].

1.1. Types of software which can be used during education

All software that can be used during the learning process in the application of STEM technology can be divided into desktop applications, mobile applications, and web-oriented technologies. The most perspective of information and communication technology (ITC) to use is augmented reality [1, 18, 21], virtual reality [2, 12, 13, 18, 20, 25, 27, 29, 38], providing of digital environments of education, including computer modeling [7, 17, 28, 30, 34], providing of centralized educational networks [31, 36], mobile-based education [22, 23], modeling environments [9, 14–16] providing of education visualization by including YouTube videos [5, 6], 3D modeling and printing, etc. Comparison of the most used in the education process software is presented in table 1.

So, using of mobile phone apps during educational process is characterized by arrays of advantages such as multi-capabilities, interaction with students in their research and visualization on the educational process. Detailly, mobile apps can be classified as measuring apps, analyzing apps, image recognition and classification apps, course platforms, VR and AR-based apps. Based on functions of apps, they can be deviated into the following categories:

- training (course) platforms;
- measuring apps;
- measuring apps;
- video analysis apps;
- applications that analyze images and classify them;
- augmented and virtual reality (AR and VR) apps.

Comparison of different mobile apps categories is shown in table 2.

Apps-identifiers characterized by high potential to especially in biology classes due possibility to provide personalized researches. Today, there is a range of mobile applications that identify wildlife. Such apps are insects- (for example, Insect identifier Photo), animals- (Dog Scanner),

Table 1
Comparison of the most used in the education process software.

Type	Web-oriented	Mobile applications	Desktop applications
Installation	Not required	From official stores or using application file	From official stores or installation files
General requirements	Compatible Internet browser for all features support	Compatible version of Android, iOS or another mobile operating system	Compatible version of Windows/macOS/Linux or another desktop operating system
Facilities	Modeling, calculation, visualization, video presenting	Modeling, calculation, visualization, video presenting, AR, measuring using both internal and external sensors, photo analysis, AR, VR	Modeling, calculation, visualization, video presenting, using additional external sensors
Main advantages	Cross-platforming, no installation required, low device space usage	Huge possibilities, mobility of usage	Stability and variation of applications
Main disadvantages	Limited opportunities, may not start correctly depending on the platform, lack of individualization	Needs technical updates which may be expensive (in two-three years may be required to buy new phone)	Lack of individualization, the lesser effect of increasing motivation during STEM education

mushrooms (Fungus) and plants-identificatory (Flora Incognita, PlantSnap, Picture This). Some apps provide identification of few type nature (both, plants and animals), for example Seek. In our opinion, most promising are applications that provide analyzing of the static objects of the nature (plants and mushrooms). It is due to lower requirements to the camera. So, they don't require high-expensive smartphones and it can be used widely during the educational process, almost in all schools.

1.2. The problem of plants identification

There are about 27,000 species of flora in Ukraine. Such biodiversity requires detailed description and study. Also, natural conditions are constantly changing, and this causes changes in the species composition of biocenosis. Both aspects indicate that there is a problem with plant identification. One of the basic principles of pedagogy is the principle of a nature experiment. For a modern child, a mobile phone with Internet access is its natural environment. So, training should be carried out in an environment, where the mobile phone should become a full-fledged learning tool.

Some apps can be installed on the student's mobile phone for free to determine the species of plants, their morphology, the range of distribution, and more.

There are about 10 applications that can be used to identify the plants. Most common of them are LeafSnap, Seek, PlantNet, Flora Incognita, PlantSnap, Picture This, Florist-X (in Russian), What is a flower (in Russian), Manager of houseplants (in Russian). These applications can

Table 2
Comparison of the most used in the education process software.

Type of application	Description	Examples
Education platforms	These platforms allow the teacher to create instructional content, communicate with students, give them assignments and check them out automatically	Google Classroom, Prometheus, Coursera, Microsoft Office 365 for Educational
Measuring applications	These sensors and their software are already built into mobile phones	Measure, AR-ruler, Smart Measure, Luxmeter, Accelerometer, Magnet Field Meter
Image analysis apps	It allows you to measure distances, angles, perimeters, areas, and calculate with this data.	ImageMeter
Image recognizing and it's classification applications that analyze images and classify them	These mobile applications allow you to identify species of plants and animals using photos	Identification, Mushroom, Shazam, Dog Scanner, Identify
VR and AR-based apps	Allow virtual travel, get a spatial image of the training material.	Minecraft Earth, IKEA Place, Ideofit, Lego Hidden Side

be divided into three gro plant identifiers that can analyze photos (Google Lens, for example, PlanNet, Flora Incognita, PlantSnap, Picture This. ups, such as:

- plant identifiers that can analyze photos (Google Lens, for example, PlanNet, Flora Incognita, PlantSnap, Picture This.
- plant classification provides the possibility to identify plants manually. The plant's classificatory commonly contains pictures and information about plant kind. But the quality of analysis, in this case, will depend on the user's knowledge and skills which may be hard for both teachers and students. Their use in biology lessons within the STEM approach has considerable potential because it allows to lean the plant morphology. However, its efficiency depends on the knowledge of user which may be lacked in case of pupils (for example, Florist-X and What is a flower).
- plants-care apps that remind water of the plant or change the soil, which characterized by the lower potential compared to other types of application (for example Manager of houseplants).

Taking into account all advantages of plant identifiers, they were used as an object of the research. It was proven that Google Lens provides high efficiency in plant type and species identification [32]. Google lens can provide analysis of real-life objects in AR and provide additional information using neural network algorithms. A few articles have devoted to Google Lens that proves its actuality to use [8, 26, 37]. However, some apps-identifiers may be more specialized and may provide better efficiency of the identification.

Despite the great specialization of other applications, hypothesize the research is that Google Lens is the best plant analyzer due to larger database, better algorithmic of analyzing and

teaching of AI using Google crowdsource app (500 000+ installation).

Therefore, the purpose of this article is to analyze existing applications, that can be used in teaching biology both in the classroom and in the field.

2. Methods of analyzing

To provide an analysis of the usability of applications related to plant identification, a survey of experts on digital didactics was provided. The main criteria were installation simplicity, level of friendliness of the interface, correctness of picture processing. Each criterion was evaluated from 0 to 5 (as higher than better). Those applications which were characterized by average evaluation more than 4 were used to further analysis on quality of identification due taken to account fact usage of the application during the educational process, where it will be used by students and teachers, both potentially with not the highest level of ICT competence.

Analysis of quality of identification was provided by a simplified method compared to our previous research due aim of this paper to obtain a general state on application plant identification accuracy. To provide it, 350 images from the list of plants of the "Dneprovskiy district of Kiev" were taken to provide analysis. The key from the "Dneprovskiy district of Kiev" plant classification was used as control. To analyze the data, tables with names of the plant as lines and as names of app in columns has created. For each successful identification at the intersections "1" has put and for each unsuccessful "0" has put (see an example in table 3).

Table 3
Example of the table of apps analyzing

The name of the plant	Flora Incognita	PlantNet
Prunus armeniaca (Apricot)	0	0
Jasione montana	0	1
Ageratum houstonianum	0	1
Chaenomeles japonica	0	0
Amaranthus	1	0
Ambrosia artemisiifolia	0	1
Amorpha fruticosa	0	0
Anemo	1	1
Anemonoides ranunculoides	1	0
Anisanthus tectorum	0	0

Finally, all obtained results, including both, general usability evaluation (survey) and results on identification quality were compared with results on Google Lens to summarize information and achieve a general and final state in this field.

3. Results

3.1. Analysis of the interaction with apps

General characteristics of the apps. The apps databases are significantly differing. The lowest number of plants in database is included in Flora Incognita (4800 species) and the highest is included in PlantSnap (585,000 species).

In additions, the apps databases differ by presence of species based on geographical locations. For example, Flora Incognita's database is very limited geographically and contains only German flora; Opposite, PlantNet's data is geographically very wide and contains flora of Western Europe, USA, Canada, Central America, Caribbean islands, Amazon, French Polynesia, including, medicinal plants, invasive plants, weeds.

Login procedure and instruction. For education, the login procedure is very important due its related to the safety of student's personal data. On the other hand, login possibility is important to save achievements, progress, and communications which motivates student.

Only LeafSnap doesn't use the additional account et al (it automatically connected to Google account). Almost all apps request their own account. Seek requests Inaturalist account (to connect with social network Inaturalist). Apps such as FloraIncognita starts from account creation page; PictureThis starts from payment page which may be a disadvantage for using by pupils. Login process of Flora Incognita, PlantNet, PlantSnap, Seek, Picture-This, and PictureThis's aggressive advertising is presented in figure 1.

The detailed video instructions are sent to the e-mail only using PlantSnap app (English voice and Russian subtitles). Other apps provide instructions in app. PlantNet does not have Instructions et al. Instructions of PictureThis's are very simple. LeafSnap's help is not displayed at the first start; it is located in a specific tab. Instructions in Flora Incognita (a), PlantSnap (b), PictureThis (c) LeafSnap (d) and Seek (e, f) apps is presented in figure 2.

Data and photo input process. According to botanical science, the algorithm for determining a plant includes: establishing the life form of the plant (tree, bush, grass); then studying the vegetative parts of the plant (leaves, stem). In addition, generative organs (flower or fruit) analysis is useful to determine a specific species name. Flora incognita and LeafSnap are provide addition of different part of the plant's pictures. The mechanism of processing can differ. For example, Flora incognita process photos of different parts of the plant; PlantNet are provides photography and then choosing of the plant part (analyzing only one photo).

Geographic location is very important to identify many species. Picea omorika and Picea abies are very similar species, but Picea omorika only in Western Siberia and Eastern Bosnia and Herzegovina. Seek, Flora Incognita, LeafSnap, PlantNet requests geolocation access during the first start. If the algorithm for determining the plant in the application includes the definition of life form, photographing the vegetative and generative organs, as well as the geographical location of the object, the algorithm has evaluated as completely correct. If the application of the plant is based on the analysis of one image in a single click, the algorithm has evaluated as simple. The interface of different apps photo and data input is presented in figure 3.

In general, all apps are free, but PlantSnap limits identifications by 25 plants per account per day. The programs can request or a single photo of the plant or photos of different parts of plants (PlantNet). LeafSnap provides automatic detection of the part of the plant presented in
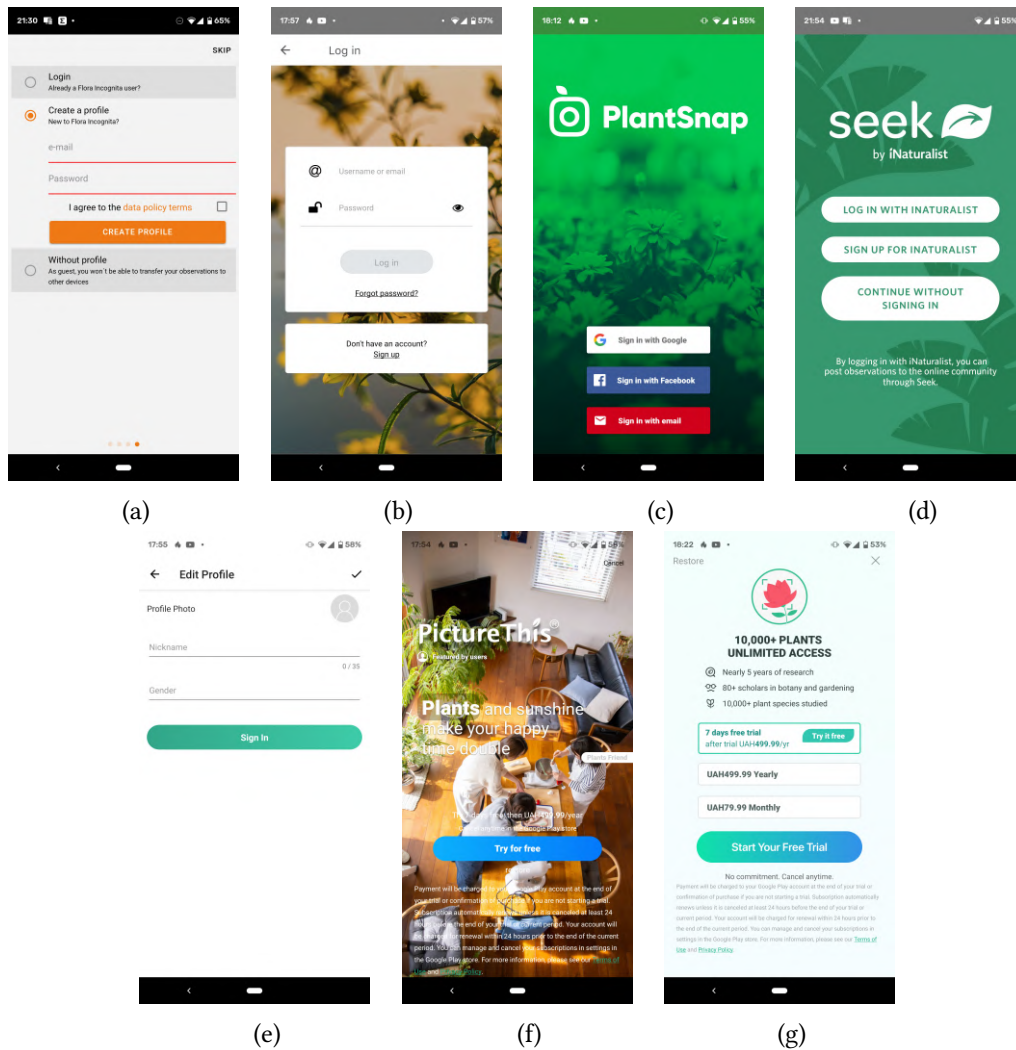
Figure 1: Login process of Flora Incognita (a), PlantNet (b), PlantSnap (c), Seek (d), Picture-This (e), and PictureThis's aggressive advertise (f, g).

the photo. In general, all programs provide the possibility of both, making a real-life photo or uploading of photo made before.

Identification results. All apps (except PlantNet and Seek) provides information on the determined plant. All data on the plant is very structured in all apps and displayed for example in style: "Genus: Fucus".

FloraIncognita, PlantNet, PlantSnap provide interaction with other sources. Both, general sources such as Wikipedia and very specific sources such as Plants for a Future are used to interact. The most interactive is Plant net. It provides links to Catalogue of Life, Plants for a Future and Wikipedia Flora Incognita, and in the case of Russian interface provides the link with site www.plantarium.ru (figure 4). Comparison results of mobile applications that can analyze plant photos are presented in table 4.
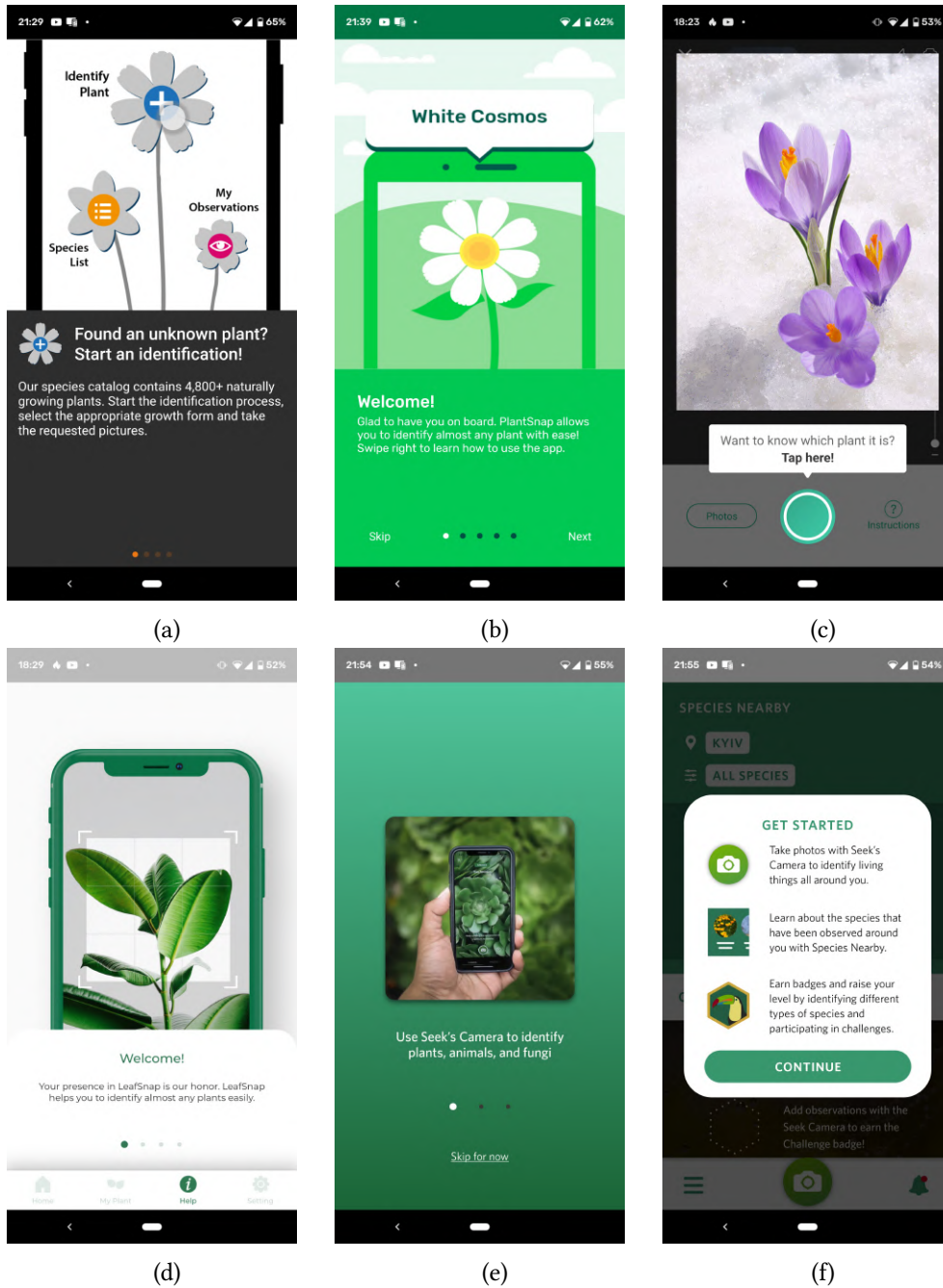
Figure 2: Instructions in Flora Incognita (a), PlantSnap (b), PictureThis (c) LeafSnap (d) and Seek (e, f) apps.

There some very specific functions during identification:

- PictureThis can provide auto diagnose of plant's problem on pests and diseases (figure 5);
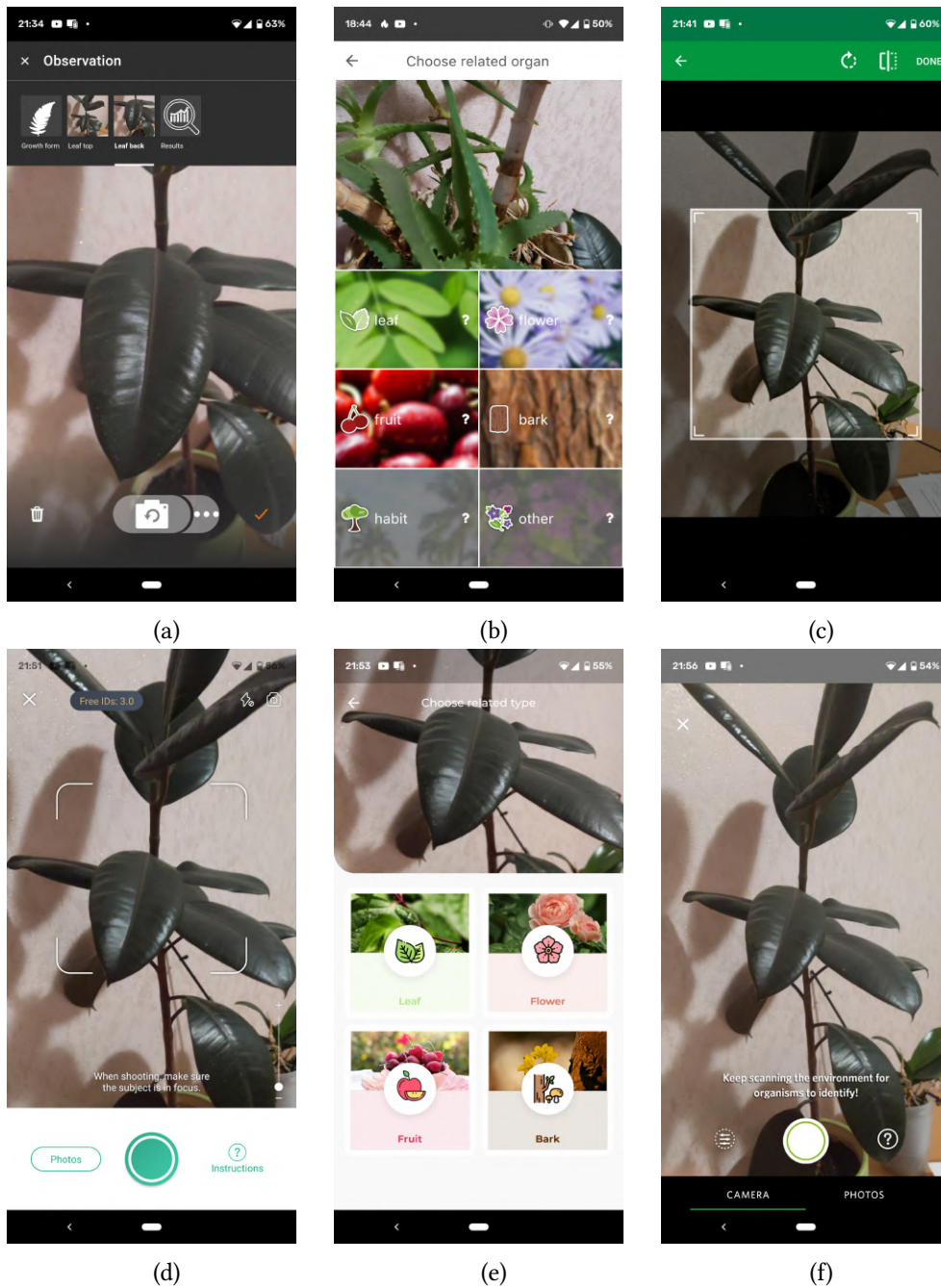
Figure 3: The interface of photo and data input of Flora Incognita (a), PlantNet (b) PlantSnap (c) PictureThis (d) LeafSnap Seek (e) apps.

- PlantSnap finds the plant at amazon and provides an infographic on solar activity, water usage and activation temperature.
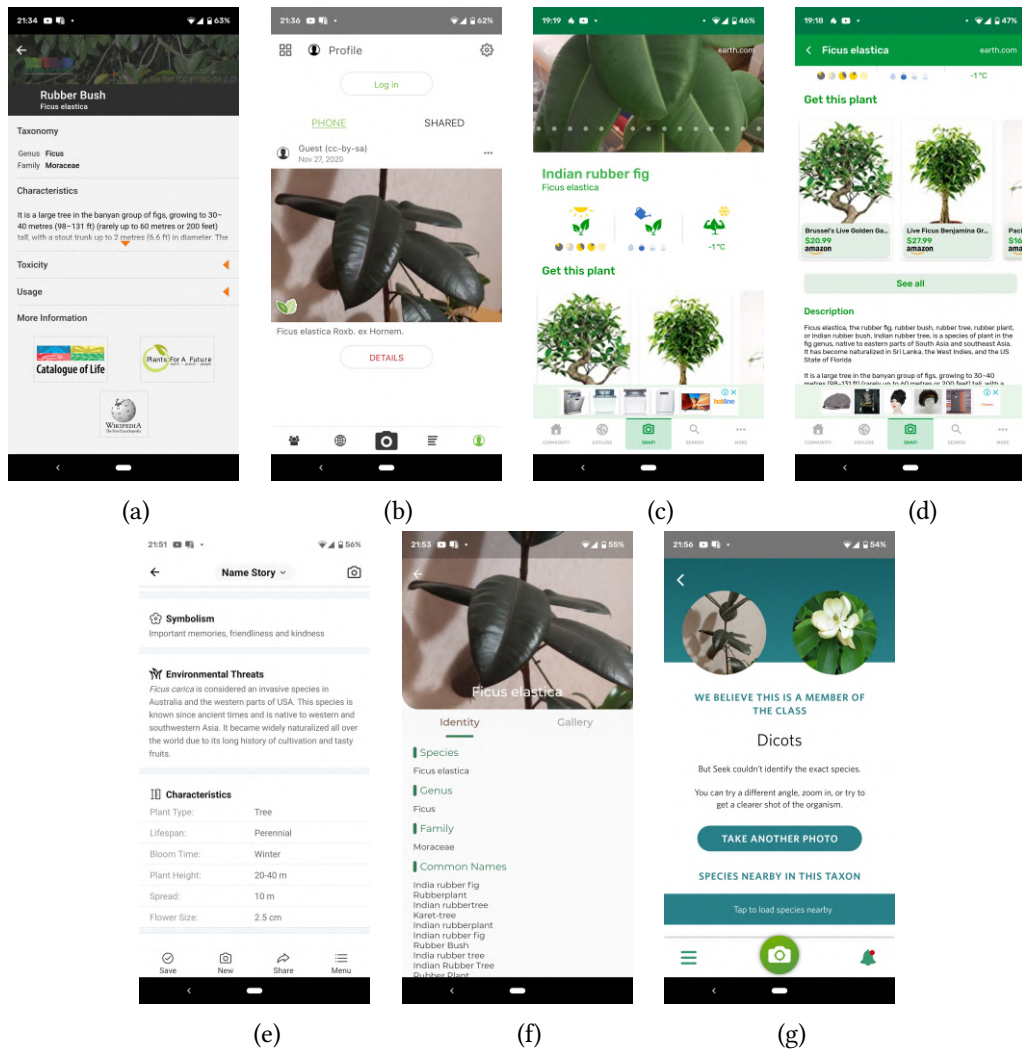
Figure 4: Data on identified plant Flora Incognita (a), PlantNet (b), PlantSnap (c, d), PictureThis (e), LeafSnap (f), and Seek (g).

3.2. Infrastructure and social environment

Some applications have their own approach to provide complex research of nature. Those features are very useful to increase the motivation of students to research nature. It's worth noting that the most developed environment is in Seek used iNaturalist application (developed by California Academy of Science and National Geographic). Which delivers to students and teachers' powerful systems of different instruments.

Photo sharing and communications. PlantNet provides the feed of photos to identify, shared by other users of PlanNet. The information in the feed is divided into classes "identified", "unidentified" and "All"-filter (displays both, identified and unidentified). The items in feed with an "identified" filter will display already identified plants by users and "unidentified" will

Table 4
Comparison results of mobile applications that can analyze plant photos.

| App title	Plants amount in database	Correctness of the analyzing process	Links with other information services
Flora Incognita	4800 (only German)	The analysis algorithm is correct	Links to Catalogue of Life, Plants for a Future and Wikipedia. Flora Incognita with Russian interface provides links to the Russian site www.plantarium.ru
PlantNet	21920	The analysis algorithm is completely correct	Only the name of the plant. Includes elements of social networks (by sharing plants student found and subscriptions). It contains links to Wikipedia.
PlantSnap	585000	The analysis algorithm is simple.	Has own description. Provides searching on Amazon to buy it.
Picture This	10000	The analysis algorithm is simple	Provides very structured information (including type, lifespan, height, flower diameter), care aspects, usage of the plant
LeafSnap	No data	The analysis algorithm is correct. Determining includes evaluation of health state (healthy and unhealthy).	Contains links to Wikipedia, Pl@ntUse, Global Biodiversity Information Facility
Seek	No data	The analysis algorithm is the simplest. The achieves are given for users after some successful identifications	Has no detailed description, but propose "species nearby in this taxon"

display not-identified pictures updated by users. The most perspective is using "unidentified" feed which may be useful in a few cases:

- To help with identifying of the plant
- To train own identification skills by providing identification of pictures of others
- To share thoughts in the field of botanic, communicate with other researchers, and to provide social science networking.

Personal journals. The first instrument to motivate is personal journals of observation and identification. This is a very common feature. For example, Flora Incognita has tab "My observations"; PictureThis has "My garden"; Leaf snap has "My plants". However, some apps do not provide explicitly personal journal. For example, PlantNet saves just the history of observations.

Projects and social. Seek provides collaboration by providing projects. Users can find and chose projects they like and join be involved in them. It's worth note, that the app is very

| (a) | (b) |
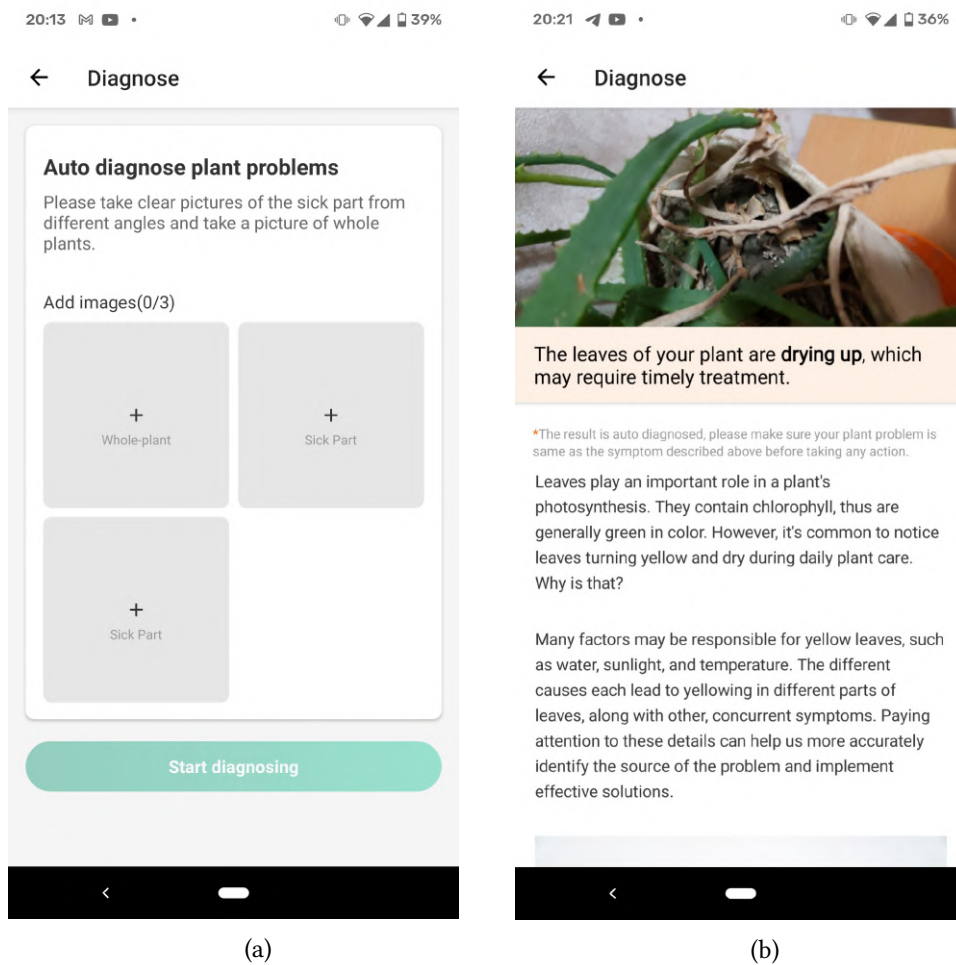
Figure 5: PictureThis' plant's auto diagnose on pests and diseases function: photo input interface (a) and the result of the analysis (b).

widespread and there are even projects in Ukraine. The interfaces of project selection and concrete project interface are presented in figure 6a.

Achievements. The Seek-identification app provides a significantly different approach to increase students' motivation. It provides achieves for each plant students found which motivates students to get new and new researches from time to time. The effect of achievement affects the brain as exaltation and people want it again and again. This is used in games to motivate students to play again [10]. In the case of Seek, some factors will motivate students to research nature.

The iNaturalist propose observing of plant and animal kinds student can find nearby. This feature is activated by the "Exploring All" function and choosing "My location". Also, based on location students can use Missions which provides quests for students to do, for example, to find "Rock Pigeon". So, students can observe nature nearby in general to study it and the program will stimulate students by completing the missions. The Exploring All and Missions

| (a) | (b) | (c) |
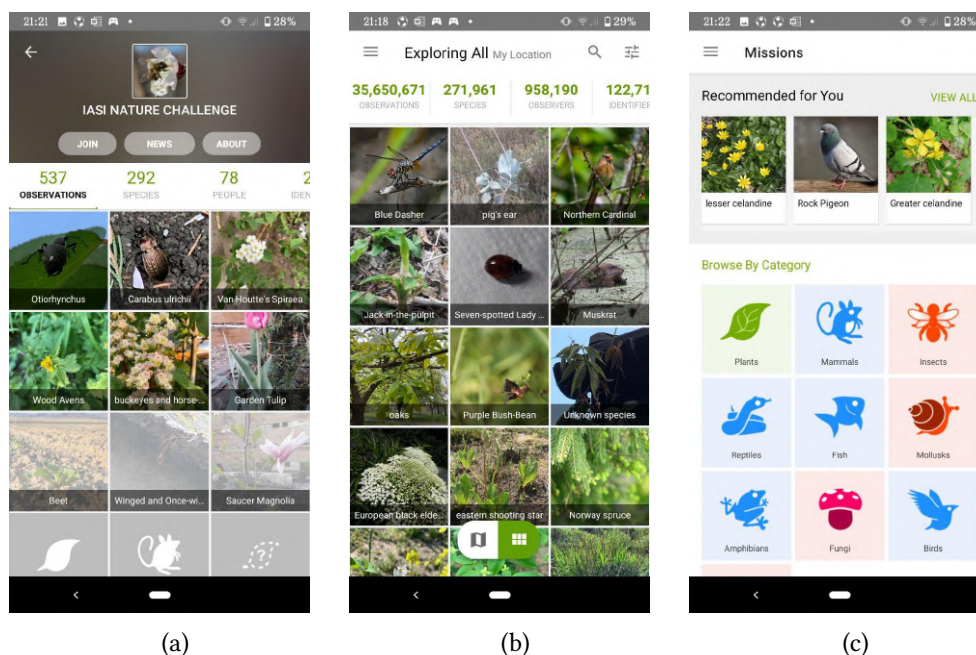
Figure 6: The Exploring All (a), Missions functions (b) and concrete project (c) functions.

functions are presented in figure 6b,c.

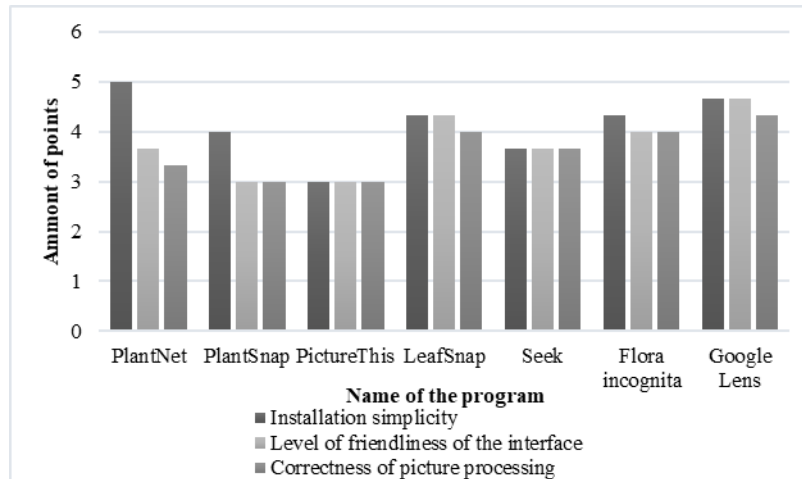### 3.3. Analysis of application identification accuracy

PlantNet is the easiest app to install. Also, pretty easy to install are Google Lens, LeafSnap and Flora Incognita. Apps Google Lens, LeafSnap, Flora Incognita, Seek to have the simplest interface. Google Lens, PlantSnap, PictureThis, and PlantNet are characterized by the most uncomfortable process of identification which can be complicated for teachers. Results of detailed analyses on plant identification applications are presented in figure 7.

In general, Google Lens, LeafSnap, Flora Incognita, PlanNet, Seek has evaluated as most usable and they were detailly researched. However, the total number of points each of the applications received is presented in figure 8.

The most accurate apps are Google Lens with 92.6% of correctness of the identification. Flora Incognita provides correct identification of 71% of cases; PlantNet – in 55%; Seek – in 76%. In our previous work, we demonstrated that Google Lens does not differentiate native species from Ukraine. It seems that Seek, PlantNet and Google Lens mostly use data of American and European kinds of plants to training the neural network and they have missed under identification of specific Ukrainian's kinds of plants. Flora Incognita was characterized by significantly different specific of analyses; it may be due to Flora Incognita uses a Russian database (similar to the Ukrainian region). This may explain a higher percent of identification accuracy of Flora Incognita, compared to PlantNet. Results on analysis quality of apps which are identified plants are presented in figure 9.

From the point of view of botanical science, the possibility to add different parts the plants

Figure 7: Results of detailed results on plants identification applications usability analysis.
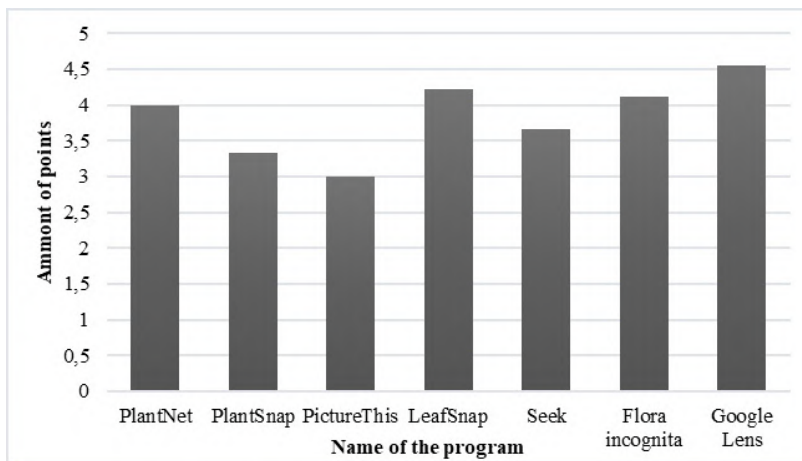
Figure 8: Integrated results on the usability of plants identification applications.

and choosing of the plant's type and geolocation access must affect the identification process correctness. However, taking to account the results of the experiment, applications with a simple algorithm definition (analysis of a single image) more accurately identify plants. It seems that internal algorithms of identification (due to higher statistical characteristics of neural network) and fullness of database is more important than correctness of data input or taking to account of geolocation.

So, Google Lens is characterized by the highest quality of analysis which may be due to the better recognition algorithm and the most trained neural network. However, it still may be relevant to use other applications in case it will be characterized by significantly higher parameters of use. To evaluate this, a similar survey as used for other plant identification applications was used for Google Lens. Google Lens has the most intuitive interface, is the most
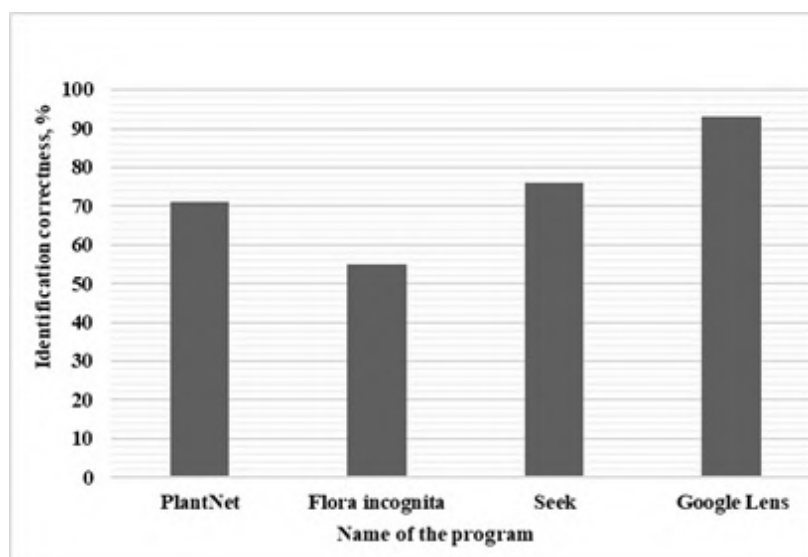
Figure 9: Results on analysis quality of apps which is identified plants.

easily loaded, and gives the most accurate definition result and therefore is characterized by the highest general evaluation with 4.6 points of interface analysis. This is significantly higher than marks for other apps.

Therefore, Google Lens is the most recommended app to use. Talking to account, results of usability analysis, and quality of analysis, for those students and teachers who do not like Google Lens app, it is possible to use Seek or Flora Incognita, but PlantNet can't be recommended to use due to low accuracy which may provide up to half of incorrect analyzing results.

3.4. Advantages of using mobile phone application in the educational process

In our opinion, the use of mobile applications that identify plants during the education process has the following functions:

1. *Creating a learning environment.* Even in the works of the classic of pedagogical thought M. Montessori [35], it was proved that the environment should develop the child. Mobile applications to a greater or lesser extent create such an environment. For example, Seek stimulates the child to search for new plant objects, manages the process of photographing plants, provides links to additional information about the plant, creates its own synopsis for the child, rewards the child with "achievement".

2. *Cognitive function.* Only 70 hours are allotted to study all plants in Ukrainian schools. There is very little time. Mobile applications allow students to learn about the diversity of the plant world.

3. *Training function.* Due to the limited number of teaching hours, the teacher cannot focus enough on the developed practical skills, such as determining the life form of plants (bush, grass, tree, vine). Such skills are developed as a result of repeated training. Some

applications, such as Flora Incognita, request a definition of life form. And this contributes to the formation of this skill.

The use of mobile applications promotes the development of students with the following competencies:

1. Competencies in the field of natural sciences, engineering, and technology [11]. When using mobile applications, students gain experience in the study of nature.
2. Environmental competence [24]. Some applications, such as Seek, explain the rules of behavior in nature.
3. Information and communication competence [19]. The use of mobile applications allows students to demonstrate the safe use of technology for learning.
4. Lifelong learning competence [4]. The use of mobile applications teaches students to find opportunities for learning and self-development throughout life.

4. Conclusion

Apps related to plant identifications can be referred to as those which can analyze photos, devoted to manual identification, and apps devoted to plant care monitoring. LeafSnap, Flora Incognita, PlanNet, Seek are the most usable plant identifiers apps during STEM-based classes.

It is shown that Google Lens characterized by the highest mark of usability compare to PlantNet, Flora Incognita, and Seek. In addition Google Lens has the highest accuracy of identification rate (92.6%). Seek and Flora Incognita has significantly lower accuracy of identification rate 76% and 71%, respectively. PlantNet provides correct identification only in 55% of case which is significantly and can't be used during education at all. Therefore, Google Lens is the most recommended app to use during biology classes. However, for those students and teachers who do not like the Google Lens app, it is possible to use Seek or Flora Incognita.

However, Google Lens provides only identification without ecosystem. The Seek mobile application can be used as a complex learning environment. It includes communications between naturalists, achievement system for motivation of the students and other advantages.

In general, it is proven that using of AR-based identification programs characterized by positive effect on education process and provides development of the competencies.

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