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DIGITISATION AND DIGITALISATION TOOLS IN THE PHARMACOGNOSY LABORATORY

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Abstract. In educational and research laboratories, where experiential learning is essential, the integration of viable teaching methods is necessary to keep up with the evolving world. This study outlines the design and integration of digital tools tailored for the Pharmacognosy laboratory at Sofia University "St. Kliment Ohridski." Using the ADDIE framework, resources including interactive laboratory report forms, a digital glossary, photographic repositories, NFC tag-enabled access points to curated online sources, and 3D models were chosen, created and integrated within the Moodle e-learning platform. A survey of students revealed positive perceptions towards these resources, with the interactive report forms rated highest for usability and impact. Although 3D models generated considerable interest, their quality concerns highlighted the need for refinement. The findings suggest that low-barrier, cost-effective tools offering direct educational support yield the greatest benefit. Overall, digital transformation in laboratory education demonstrates clear potential to enhance accessibility, efficiency, and engagement.

Keywords: digitisation; digitalisation; higher education; pharmacognosy; laboratory workflow

Introduction

Digitisation and digitalisation are purposeful approaches which drive higher education towards transitioning from a purely physical to a virtual world. These processes are carried out not only as a means to streamline the educational process in the reality of an ever more sophisticated curriculum (Rhoney et al., 2021) but as strategic goals set at the national[2] and international[3] level. As technology advances, so should our understanding of the capabilities of the tools we utilize and the opportunities that they present. A potential first step towards this is the digitisation of available analog data. Although physical data storage methods are arguably more durable (Hooper, 2021), digital data has the advantage of being easy to access and disseminate, which is one of the factors driving the processes of digitalisation (Lee et al., 2002). Creating virtual classroom activities for distance learning; interactive live inventories for the laboratory; digitized instructions and other helpful information, such as readily available operating procedures for different experiments and apparatuses; sample and terminological glossaries, etc.; are all examples of workflow optimization both for students engaged in experiential learning and any academic research carried out within the laboratory, dependent on digital tools (Renn et al., 2018).

Several attempts at implementing this approach have been carried out. Examples include the implementation of automated specimen tracking and digital ready slides in Pathology laboratories (Schwen et al., 2023); improving lab-to-lab communication (Comeaga, 2022), inventory management through the creation of live databanks (Rihm et al., 2024), standard operating procedures and results documentation through electronic laboratory notebooks (Gerlach et al, 2019), etc. The goal of these efforts have been directed at improving research output, but they do not necessarily take into consideration the potential impacts in laboratories geared towards education as well as academic work. It appears that the majority of digitisation and digitalisation work relating to student education has been aimed at improving existing physical resources by supporting access to educational methods such as the implementation of websites and social networks (Mukhametgaliyeva et al., 2022) (e.g. digital learning platforms) and little work has been done in an effort to bridge the gap between experiential laboratory learning and digital access to resources housed in the laboratory. An important consideration is that digital resources as well as the processes of digitisation and digitalisation are likely to be specific to the course subject matter as well as the facilities in which experiential learning is carried out (Rihm et al., 2024). Pharmacognosy is a core discipline in the master's program in Pharmacy taught at Sofia University "St. Kliment Ohridski", Faculty of Chemistry and Pharmacy. According to the course outline Pharmacognosy is a multidisciplinary science, exploring natural compounds as sources for the development of medicinal, borderline and other products[4]. The practicums in Pharmacognosy have students performing complex experiments which require an in-depth understanding of different biological, chemical and physiochemical concepts as well as adhere to well-structured standard operating procedures in order to facilitate the effective acquisition of skills required for the identification, authentication, quality analysis and use of natural compounds[5] (Stoyanov, 2024). So far in the Pharmacognosy laboratory of the Department of Chemistry and Pharmacy of the Faculty of Chemistry and Pharmacy at Sofia University "St. Kliment Ohridski", the majority of these resources have remained accessible only on physical format (e.g. herbarium specimens, dried herbal substances, operational manuals and laboratory guides, unstructured hand-written laboratory reports, etc.). Strides have been made to digitize the herbarium and herbal substance collection by creating a gallery of photographic materials, however a method to readily access these materials has not been crafted. Classical digital learning resources like lecture materials and textbooks, as well as student result evaluation methods have been implemented by leveraging the university's online learning platform – Moodle. However, highly rated, modern educational methods have not been introduced. Thus, the goal of this work is to define and evaluate digitisation and digitalisation tools for the Pharmacognosy, taking into account the cost of implementation in terms of labor hours required to craft and introduce a defined set.

Digital tools have inherently different drawbacks and advantages. Careful consideration of these is paramount to their successful implementation within the workflow of the Pharmacognosy laboratory (DiVall et al., 2013). Usually, a priority is finding low-cost tools. This can be interpreted as the tool itself being easy to implement or requiring little to no financial investment (Dugan et al., 2000). Student predisposition to digital tools should also be taken into account. A tend has been demonstrated towards the preferred use of smart devices such as phones, as opposed to desktop computers, in contrast to desktop computers being better mediums for performing tasks (Adepu & Adler, 2016). Furthermore, the Pharmacognosy laboratory is not capable of supporting larger personal electronic devices. This frames the exploration within the confines of a narrow spectrum of unobstructive tools, when discussing physical points of interaction with the digital tools. The student body is increasingly more diverse in terms of acquired skills prior to the start of higher education. Thus, it is prudent to assume that low-barrier of entry tools would have greater impact and higher engagement. In term of threats one ever persistent hazard is the risk of data breaches and integrity loss (Cremer et al., 2022). The dynamic, live nature of these tools also increases the risk of loss of backwards compatibility (e.g. updating software or hardware makes already created and implemented resources incompatible or otherwise inaccessible) (Ponomarenko & Rubanov, 2012). Thus, striking a balance between low-cost, high-efficiency tools, which are low-barrier of entry for users in tandem with having high impact on education and few associated risks is crucial. A summary of these considerations available in the published literature is provided in Table 1 in the form of a SWOT analysis.

Table 1. SWOT analysis of key considerations regarding the digitisation and digitalisation of laboratory workflow as outlined in published literature

Strengths	Weaknesses
Enhanced accessibility through remote participation (Hunter, 2015) Cost savings on consumables and equipment wear (Abdel-Aty et al, 2024) Improved data storage, accuracy and automation (Comeaga, 2022) Scalability for large student cohorts (Renn et al., 2018.) Enhanced laboratory workflow (Schwen et al., 2023.) Hybrid education models combining virtual and physical labs (Son et al, 2016)	Initial setup and training costs (Lopes et al, 2023) Technical limitations for certain equipment (Mhlongo et al., 2023) Reduced hands-on experience (Zhang et al, 2021) Learning curve for students and faculty staff (Elliott & Kukula, 2007) Ongoing maintenance and required updates (Kurtz et al, 2025)
Opportunities	**Threats**
Empowering rapid researcher collaboration (Rihm et al, 2024) Integration of artificial intelligence and virtual reality for immersive learning (Costabile et al., 2025) Adding computational systems that process and store data in real time (Stoyanov et al, 2025) Using devices that collect and share data over the internet (Jovičić & Viktus, 2023)	Cybersecurity risks and data breaches (Cremer et al., 2022) Digital divide and unequal access (Jafar et al, 2024) Rapid software and hardware planned or accidental obsolescence (Ponomarenko & Rubanov, 2012) Resistance to adopting new technologies (DiVall et al., 2013) Dependence on external vendors (Zhang & Huo, 2013)

Methods

The ADDIE model was used to correctly assess which tools were needed and how they performed in terms of helping the educational process. ADDIE is a five-step framework for instructional design that stands for Analysis, Design, Development, Implementation, and Evaluation, developed by Branson et al. (1975). Several modern digital tools were highlighted as perspective when ADDIE was applied to the Pharmacognosy laboratory educational and research workflow.

The online e-learning platform developed for Sofia University "St. Kliment Ohridski", powered by Moodle, is highlighted as an intuitive, secure and easy to access virtual interface and storage for terminological, photographic, video, etc. repositories (Rakić et al., 2020). The varying activities and modules supported by the platform are leveraged for the implementation of all other digital tools. Several digital repositories were created to support the rest of the selected digital tools. A complete inventory database of all herbaria, herbal substances, reagents and solvents and a glossary of Pharmacognostic nomenclature were created. Digital copies of apparatuses user manuals were uploaded to an accessible cloud storage, accompanied by videos of device specific relevant operating procedures. The same storage functionality was leveraged to embed live three dimensional (3D) models of herbal substances and plants, and interactive student laboratory report forms on the course page.

Near-field communication (NFC) tags have been used to enable communication between two devices in close proximity (Žurbi & Gregor-Svetec, 2024). One of these is equipped with an NFC reader, while the other device is the NFC tag itself that transmits prerecorded data. Most modern smartphones have such functionality for receiving, reading and programming such data (Vazquez-Briseno et al., 2012). This posits NFC tags as intuitive and easy to use and maintain, which is why they were selected as the physical tool through which to access digitized resources within the laboratory. Additionally, NFC tags are relatively inexpensive and come in a variety of sizes and colours, which is in line with our criteria for minimally obstructive hardware. A total of 20 NFC tags were placed in strategic stops throughout the laboratory as shown in Figure 1. The setup of the tags was carried out with the mobile app NFC tools by wakdev (last updated in May 2025).

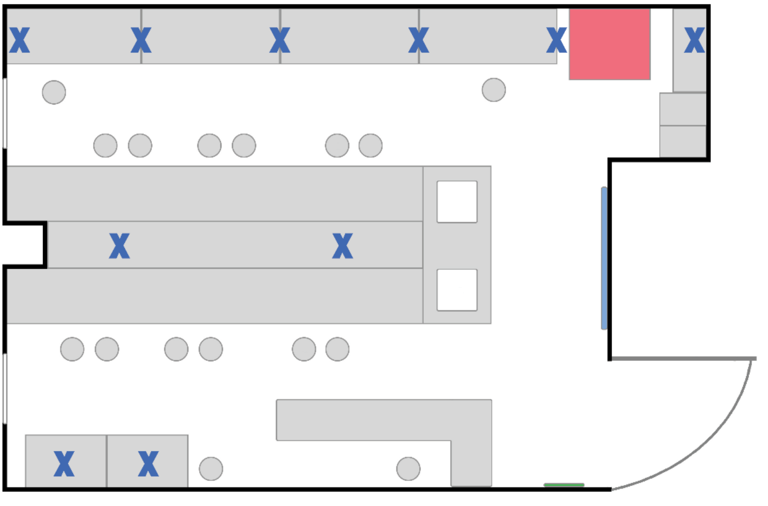


Figure 1. Layout of Pharmacognosy laboratory 412. The locations of NFC tags is shown with an X symbol on the schematic

3D models of plants and herbal substances included in the Pharmacognosy courses and published prior to the 10th of August on the Sketchfab open repository were searched for and evaluated. The search terms included the entire species name of the plant in Latin, the generic name of the plant and common vernacular name of the plant in English. The Pharmacognostic Latin and common name of the herbal substance were also included in the search terms. Discovered models were evaluated based on their level of detail as it relates to Pharmacognostic examination of natural sources. Useful models for teaching were required to display either of the three – 1) the habit of the plant, 2) general morphology (e.g. leaf shape, stem branching, etc.), 3) detailed morphology (e.g. flower structure, presence and location of trichomes, etc.). Hyperlinks leading to the model in the database were recorded and embedding codes were generated for use in Moodle using Sketchfab's built in features. In addition, several attempts at creating personalized 3D models were made with a Samsung Galaxy A34, leveraging RealityScan Mobile 1.7.1 from Epic Games International (Kozov & Ivanova, 2023), following provided instructional resources[6]. This software is free to use for educational institutions and suited to mobile devices. It was favoured for being equipped with all the tools needed to create photogrammetric models and based on personal experience, faster than manual generation with applications like Meshroom 2025.1.0, or Blender v4.5.3 LTS.

Interactive PDF forms have been adapted as an industry standard in Pharmacy (Qiu et al., 2024) and require a basic working knowledge of text editors and Adobe software to create. Interactive PDF laboratory report forms were created with Adobe Acrobat Pro 25.001.20672 to reflect this practice in practicum experiential learning. These can be filled on a personal device by students and submitted on the Moodle platform for evaluation by educators. They offer the opportunity for both textual and graphical input and are Practicum specific – i.e. reflect the unique tasks and experiments caried out and were highlighted as another affordable and easy to implement digitalisation tool.

After structured access to these resources was made available, 18 students who successfully took the final exams from the Pharmacognosy courses were invited to interact with the implemented digital tools and fill in a questionnaire aiming to evaluate their perceptions of these tools. The questionnaire contains 10 questions. Question 1 to 9 collected quantitative and question 10 collected qualitative data. The quantitative data was collected as a standard array from 1 to 5. Qualitative data was collected in the form of unstructured textual input. With the lowest value being the worst and the highest value being the best. The complete structure of the questionnaire is available in Table 2. Results were obtained from a total of 7 respondents. The survey was completely anonymous, and no personal data was collected from respondents. Integrity was assured by carrying out the survey on the course page in Moodle where the digital resources were published and made available and only one response per course participant was permitted.

Table 2. Student questionnaire structure

Question order	Question text
1	What is your opinion about the introduction of digitalisation into the educational process?
2	How easy is it to navigate through the exercise-related materials you reviewed?
3	How convenient is the numbering system for herbarium specimens?
4	How useful is it to have a 3D image of the plants being examined?
5	How good are 3D models compared to looking at real samples?
6	How easy is it to navigate through the dictionary you looked at?
7	How convenient do you find a dictionary that includes the names of the plants under consideration along with photographs?
8	How easy to use is the practicum related laboratory report form?
9	How convenient do you find an interactive laboratory report form?
10	Do you wish to express anything further considering the reviewed digital tools?

Developing these digital tools requires labor intensive work, hardware and software skills and established digital proficiencies, which differed for each approach. Because all these tools were created with overview of Pharmacognosy practicums – an inherent proficiency in Pharmacognosy is implied. These efforts are summarized in Table 3.

Table 3. Summary of efforts required to create and implement the selected digital tools for the Pharmacognostic laboratory

Digital tool	Required skills and proficiencies	Total labor hours including conceptualization and implementation
Inventory databases	Spreadsheet editing software Moodle activity editing	98
Placement of NFC tags	Selected programing software Moodle activity editing	2
Glossary of terms	Moodle activity editing	24
Photographic material gallery – herbarium collection	Photography Image optimization software	122
Photographic material gallery – herbal substance collection	Photography Image optimization software Software for micromorphological examination Moodle activity editing	133
3D photogrammetric model sourcing	Database searching Working with HTML embedding codes Moodle activity editing	47

3D photogrammetric model creation	Photogrammetry software Photography Moodle activity editing	210
Interactive laboratory forms	Text editing software Preparing interactive forms Moodle activity editing	54

Results

Digitisation of Pharmacognosy course resources as well as on site laboratory materials generated hundreds of data entries for the newly created databases. The largest database was that of the herbal substance collections curated and maintained in the Pharmacognostic laboratory. After complete itemization it stands represented by 441 unique entries, followed closely by the glossary of Pharmacognostic nomenclature which has 292 unique entries. In practical terms this means that the laboratory has 441 dried herbal substances, and 292 herbal substances are studied theoretically – of these 138 are examined in the course of student's practical work. These have their own dedicated gallery of photographic materials, which was incorporated into the glossary. The herbarium digital inventory is comprised of 280 unique entries for which 177 photographic materials have been developed. The reagents and solvents inventory features 95 entries. A total of 10 user manuals and guidelines were sourced from the manufacturers of the Pharmacognostic laboratory equipment and were made available, covering the entire range of utilized apparatuses for educational and academic pursuits. Examples of these digital tools are shown in Figure 2, Figure 3 and Figure 4

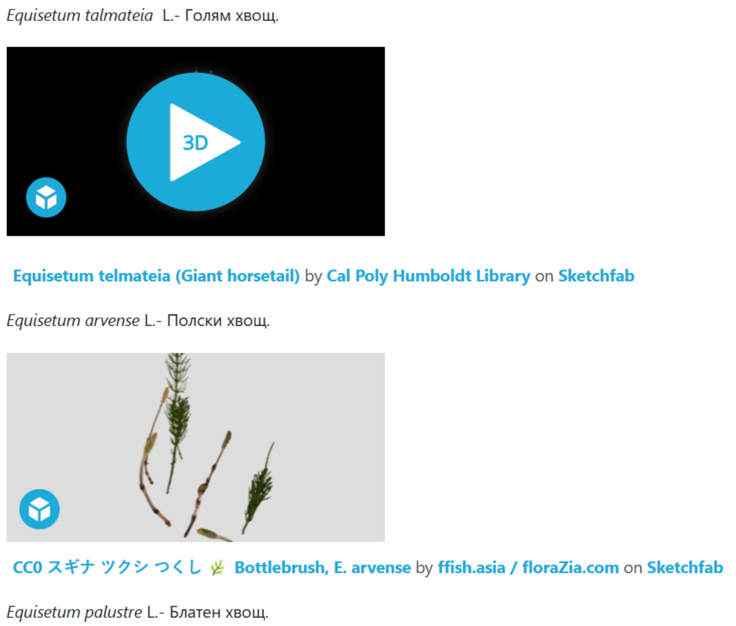
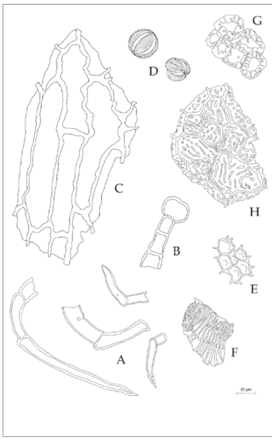


Figure 2. 3D photogram metric models of *Equisetum* spp. embedded on the Pharmacognosy course page

аврамово дърво/agnus castus

Vitex agnus-castus

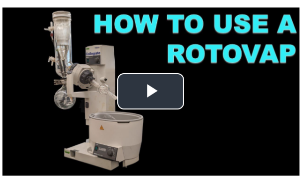


A. Покривни трихоми (Covering trichomes)
B. Жлезисти трихоми (Glandular trichomes)
C. Клетки на епидермиса (Epidermal cells)
D. Поленови зърна (Pollen grains)
E. Епидермис от венче, с папили (Petal epidermis with papillae)
F. Набраздена паренхимна тъкан (Striated parenchymatous tissue)
G. Склереиди (Sclereids)
H. Септирана паренхимна тъкан (Septate parenchymatous tissue)

Keyword(s): Lamiaceae

Figure 3. Data entry for *Vitex agnus-castus* L. in the Pharmacognostic nomenclature glossary, showcasing an original microscopic diagnostic characteristic labelled illustration

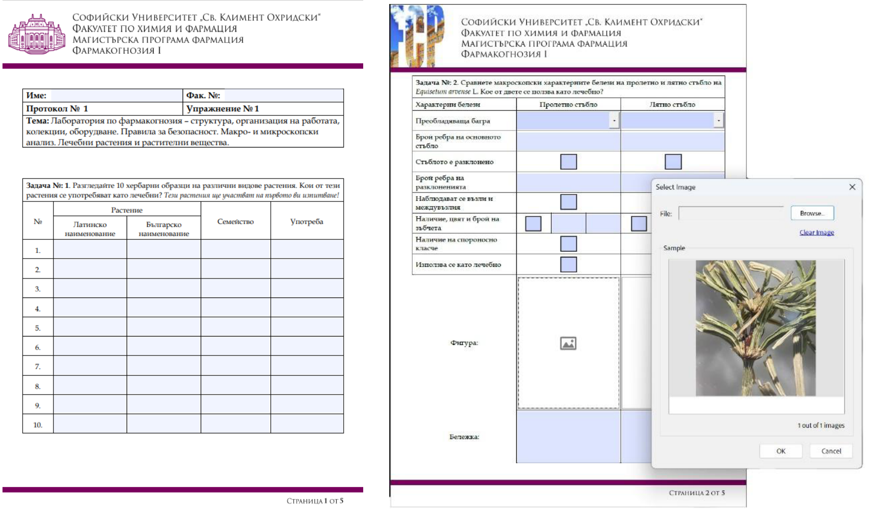
Rotavapor® R-100 Manual PDF



Substance	Vapor Pressure (kPa)	Vapor Pressure (mBar)	Temperature (°C)
Ethylene glycol	0.9	9.13	50
Water	4.2	42	50
Toluene	4.8	48	50
Methanol	21.8	218	50
Acetone	37.0	370	50
Benzene	16.2	162	50
Isopropyl alcohol	7.8	78	50
Diethyl ether	83.8	838	50
Ethanol	9.7	97	50

Figure 4. User manual and dedicated video guide and reference values for the process of extract concentration by means of rotary evaporation

A total of 10 interactable PDF laboratory report forms were crafted. A portion of the laboratory form prepared for submission after Practicum 1 in Pharmacognosy 1 is depicted in Figure 5.



Софийски Университет „Св. Климент Охридски"
Факултет по химия и фармация
Магистърска програма фармация
Фармакогнозия I

Име:	**Фак. №:**
Протокол № 1	**Упражнение № 1**
Тема: Лаборатория по фармакогнозия – структура, организация на работата, колекции, оборудване. Правила за безопасност. Макро- и микроскопски анализ. Лечебни растения и растителни вещества.	

Задача №: 1. Разгледайте 10 хербарни образци на различни видове растения. Кои от тези растения се употребяват като лечебни? *Тези растения ще участват на първото ви изпитване!*

№	Растение		Семейство	Употреба
	Латинско наименование	Българско наименование		
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

Страница 1 от 5

Софийски Университет „Св. Климент Охридски"
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Фармакогнозия I

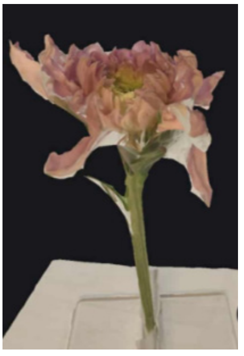
Задача №: 2. Сравнете макроскопски характерните белези на пролетно и лятно стъбло на *Equisetum arvense* L. Кое от двете се ползва като лечебно?

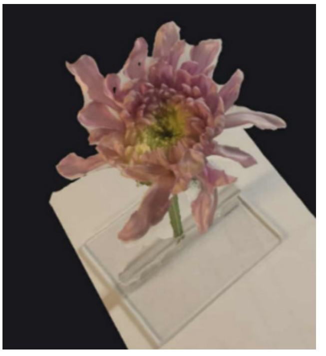
Характерни белези	Пролетно стъбло	Лятно стъбло
Преобладаваща багра		
Брой ребра на основното стъбло		
Стъблото е разклонено		
Брой ребра на разклоненията		
Наблюдават се възли и междувъзлия		
Наличие, цвят и брой на зъбчета		
Наличие на спороносно класче		
Използва се като лечебно		
Фигура:		
Бележка:		

Страница 2 от 5

Figure 5. Pages 1 and 2 (of 5) of the provided to students interactive laboratory report form. The coloured fields are intended for textual input or selection from a pre-defined dropdown menu or checkbox, whereas white boxes execute JavaScript which allows for attaching images, illustrations or other graphical materials

The Sketchfab search yielded a total of 105 available unique 3D models of plants and herbal substances studied in the Pharmacognosy course. Based on the defined selection criteria Most of the models showcased the basic morphological features of the plants and herbal substances (66, 62.9%), followed by models showcasing detailed morphology (47, 44.8%) and habitus (42, 40.0%). Creating personalized 3D photogrammetric models of herbal substances or plants proved challenging with the available materials. Out of 24 dedicated attempts, only one yielded a semi-successful model of a *Chrysanthemum morifolium* Ramat. sensu lato inflorescence provided in Figure 6. Despite managing to capture the general morphology of the inflorescence, model creation attempts were thwarted by failing to remove artifacts post processing. The current prevailing hypothesis as to the failure to create a clean 3D model has to do with the lack of a suitable, well-lit background.





a) b)

Figure 6. Personalized 3D photogrammetric model of *Chrysanthemum morifolium* Ramat. sensu lato inflorescence

Questionnaire results reveal a significant interest from students towards the use of the selected modern digital tools in the Pharmacognostic practicums. Responses were overwhelmingly positive with the average score achieved across the entire survey being 4.17. Respondents gave the highest score on question 8, which had to do with the interactive laboratory report form and specifically dealt with their perception of its ease of use. Other questions with high results (an average score of 4.9) asked respondents about their perception of the ease of navigation of the provided digital tools and the usefulness of 3D models. Conversely, lower results were given regarding the system for herbarium categorization and the convenience of having a Pharmacognostic glossary in tandem with a photographic material gallery. The lowest result obtained was on the question asking respondents to rate the quality of the 3D models. These responses suggest there is inherent potential in plant and herbal substance 3D models use in education, but more work is needed in order to produce high quality educational resources needed in Pharmacognosy education. In hindsight of the cost in terms of labor hours, described in Methods, emphasis is placed on prioritizing other digital tools for incorporation into Pharmacognosy education. A similar case can be made for the implementation of photographic material galleries, which are skill and labor intensive to build but were valued lower by students overall. Unfortunately, qualitative data failed to provide further insight into student perceptions, as only one response was submitted and read “Поздравления за добрата работа!”, which translates to “Congratulations on the work carried out!”. A complete overview of survey results is provided in Table 4 and visualized in Figure 7.

Table 4. Student perceptions questionnaire responses

Question	Responses					
	1	**2**	**3**	**4**	**5**	**Average score**
1	1 (14%)	0	1 (14%)	0	5 (71%)	4.1
2	0	0	0	1 (14%)	6 (86%)	4.9
3	2 (29%)	0	2 (29%)	0	3 (43%)	3.3
4	0	0	0	1 (14%)	6 (86%)	4.9
5	3 (43%)	1 (14%)	0	2 (29%)	1 (14%)	2.6
6	0	0	0	1 (14%)	6 (86%)	4.9
7	1 (14%)	0	3 (43%)	1 (14%)	2 (29%)	3.4
8	0	0	0	0	7 (100%)	5
9	1 (14%)	0	0	0	6 (86%)	4.4

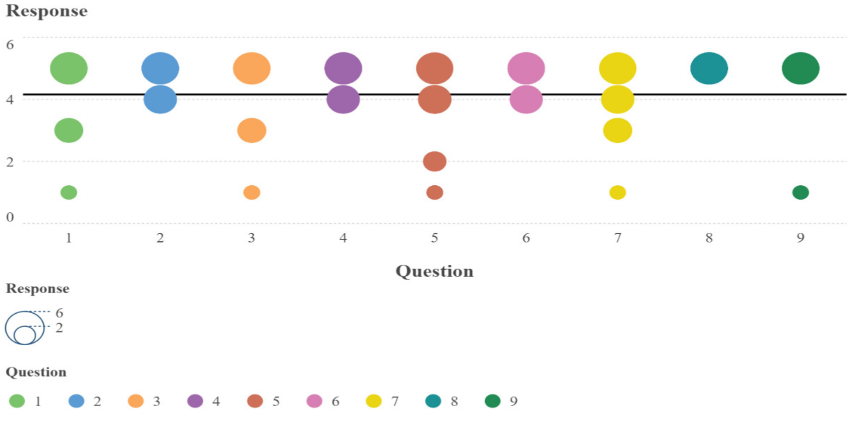


Figure 7. Visualization of responses obtained in student perceptions questionnaire. The black horizontal line represents the total average score achieved across the entire questionnaire (4.17)

Conclusions and summary

Digitisation and digitalisation are dynamic and perpetual processes. Student perceptions reveal a budding receptivity to modern digital tools and serve as a source of direction in hindsight of the practical aspects of their implementation in experiential learning. A balance between quality, ease of use, ease of navigation, ease of access, security, labor intensity and maintenance is necessary for rational incorporation of digital tools in a laboratory geared towards education as well as research. Specifically, for Pharmacognosy it appears that digital tools that offer direct structured support for students, like fillable laboratory report templates, are perceived as the most valuable by students, while at the same time being some of the least demanding in terms of required proficiency. The novelty of 3D photogrammetric plant and herbal substance models does not seem to outweigh student perceptions of their quality which reflects the author's own evaluation. Further research is required in order to frame these attempts in the context of course outcome impact and student academic performance.

NOTES

1. Second Prize in the 2nd "Natural Sciences and Innovation in Education" Research Paper Competition, dedicated to the 140th Anniversary of the Birth of Prof. Dimitar Balarew
2. Strategy for the development of higher education in the Republic of Bulgaria 2021-2030. https://www.neaa.government.bg/images/strategicheski-dok-VO/rMS_Strategia-VO_120121.pdf
3. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on a European Strategy for Universities. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022DC0016
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5. Sofia University "St. Kliment Ohridski" Faculty of Chemistry and Pharmacy, Masters Program for Pharmacy, Pharmacognosy 1 – 3260
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REFERENCES

Abdel-Aty, T. A., McFarlane, D., Brooks, S., Salter, L., Abubakar, A. S., Evans, S., Hawkridge, G., Price Thomas, K., Negri, E., Mukherjee, A., Yilmaz, G., & Macchi, M. (2024). The Role of Low-Cost Digital Solutions in Supporting Industrial Sustainability. *Sustainability, 16*(3), 1301. https://doi.org/10.3390/su16031301.

Adepu, S., & Adler, R. (2016). A Comparison of Performance and Preference on Mobile Devices vs. Desktop Computers. *IEEE 7th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON)*, 1 – 7. https://doi.org/10.1109/UEMCON.2016.7777808.

Branson, R. K., Rayner, G. T., Cox, J. L., Furman, J. P., King, F. J., & Hannum, W. H. (1975). Interservice Procedures for Instructional Systems Development. *Educational Technology, 18*(3), 11 – 14. https://www.jstor.org/stable/44418942.

Comeaga, M. (2022). Digital Transformation of the Laboratories. *IOP Conference Series: Materials Science and Engineering, 1268*, 012001. https://doi.org/10.1088/1757-899X/1268/1/012001.

Costabile, M., Caruso, C., Della Vedova, C., Bailey, S., & Mahdi, L. (2025). Leveraging Computer-based Simulations and Immersive Software Technologies for Enhanced Student Learning in Laboratory Medicine. *American Physiological Society, 49*(6), 338 – 351. https://doi.org/10.1152/advan.00128.2024.

Cremer, F., Sheehan, B., Fortmann, M., Kia, A. N., Mullins, M., Murphy, F., & Materne, S. (2022). Cyber Risk and Cybersecurity: A Systematic Review of Data Availability. *Geneva Papers on Risk and Insurance – Issues and Practice, 47*(3), 698 – 736. https://doi.org/10.1057/s41288-022-00266-6.

DiVall, M. V., Hayney, M. S., Marsh, W., Neville, M. W., O'Barr, S., Sheets, E. D., & Calhoun, L. D. (2013). Perceptions of Pharmacy Students, Faculty members, and Administrators on the Use of Technology in the Classroom. *American Journal of Pharmaceutical Education, 77*(4), 75. https://doi.org/10.5688/ajpe77475.

Dugan, J. B., Sullivan, K. J., & Coppit, D. (2000). Developing a Low-cost High-quality Software Tool for Dynamic Fault-tree Analysis. *IEEE Transactions on Reliability, 49*(1), 49 – 59. https://doi.org/10.1109/24.855536.

Elliott, S. & Kukula, E. (2007). The Challenges Associated with Laboratory-Based Distance Education. *Educause Quarterly*, (1), 37 – 42. https://er.educause.edu/articles/2007/2/the-challenges-associated-with-laboratorybased-distance-education.

Gerlach, B., Untucht, C., & Stefan, A. (2019). Electronic Lab Notebooks and Experimental Design Assistants. In: A. Bespalov, M. Michel, T. Steckler (Eds.), *Handbook of Experimental Pharmacology, 257* (pp. 257 – 275). https://doi.org/10.1007/164_2019_287.

Hunter, P. (2015). The Virtual University: Digital Tools for e-learning and Remote Learning are Becoming an Increasingly Important Tool for

Teaching at Universities. *EMBO Reports, 16*(2), 146 – 148. https://doi.org/10.15252/embr.201440016.

Hooper, L. K. (2021). Microfilm Collection Condition Assessment: An Experiential Report. *Collection Management, 46*(2), 157 – 169. https://doi.org/10.1080/01462679.2020.1859032.

Jafar, Z., Quick, J. D., Rimányi, E., & Musuka, G. (2024). Social Media and Digital Inequity: Reducing Health Inequities by Closing the Digital Divide. *International Journal of Environmental Research and Public Health, 21*(11), 1420. https://doi.org/10.3390/ijerph21111420.

Jovičić, S. & Vitkus, D. (2023). Digital Transformation towards the Clinical Laboratory of the Future. Perspectives for the Next Decade. *Clinical Chemistry and Laboratory Medicine (CCLM), 61*(4), 567 – 569. https://doi.org/10.1515/cclm-2023-0001.

Kozov, V., & Ivanova, B. (2023). Augmenting Student Education Using the RealityScan Application for Generating 3D Content. *2023 46th MIPRO ICT and Electronics Convention (MIPRO)*, 619 – 624. https://doi.org/10.23919/MIPRO57284.2023.10159773.

Kurtz, M., Benabbou, A., Pons, C., & Broisin, J. (2025). Collaboration in Virtual and Remote Laboratories for Education: A Systematic Literature Review. *International Journal of Computer-Supported Collaborative Learning, 20*, 549 – 603. https://doi.org/10.1007/s11412-025-09454-7.

Lee, K. H., Slattery, O., Lu, R., Tang, X., & McCrary, V. (2002). The State of the Art and Practice in Digital Preservation. *Journal of Research of the National Institute of Standards and Technology, 107*(1), 93 – 106. https://doi.org/10.6028/jres.107.010.

Lopes, A. S., Sargento, A., & Farto, J. (2023). Training in Digital Skills – The Perspective of Workers in Public Sector. *Sustainability, 15*(13), 10577. https://doi.org/10.3390/su151310577.

Mhlongo, S., Mbatha, K., Ramatsetse, B., & Dlamini, R. (2023). Challenges, Opportunities, and prospects of Adopting and Using Smart Digital Technologies in Learning Environments: An Iterative Review. *Heliyon, 9*(6), e16348. https://doi.org/10.1016/j.heliyon.2023.e16348.

Mukhametgaliyeva, S., Gura, A., Dudnik, O., & Khudarova, A. (2022). The Use of Social Networks in e-learning Technologies in the Context of Distance Education. *Sustainability, 14*(14), 8949. https://doi.org/10.3390/su14148949.

Ponomarenko, A., & Rubanov, V. (2012). Backward Compatibility of Software Interfaces: Steps towards Automatic Verification. *Programming and Computer Software, 38*, 257 – 267. https://doi.org/10.1134/S0361768812050052.

Qiu, L., Duan, Y., Zhou, Y., Xu, F., Zheng, H., Cai, X., & Jiang, Z. (2024). Impact of Digital Empowerment on Labor Employment in Manufacturing Enterprises: Evidence from China. *Heliyon, 10*(8), e29040. https://doi.org/10.1016/j.heliyon.2024.e29040.

Rakić, S., Tasic, N., Marjanovic, U., Softic, S., Lüftenegger, E., & Turcin, I. (2020). Student Performance on an e-learning Platform: Mixed Method Approach. *International Journal of Emerging Technologies in Learning, 15*(2), 187 – 203. https://doi.org/10.3991/ijet.v15i02.11646.

Rhoney, D. H., Singleton, S., Nelson, N. R., Anderson, S. M., & Hubal, R. (2021). Forces Driving Change in Pharmacy Education: Opportunities to Take Academic, Social, Technological, Economic, and Political into the Future. *Journal of the American College of Clinical Pharmacy, 4*(5), 639 – 651. https://doi.org/10.1002/jac5.1407.

Renn, O., Dolenc, J., & Schnabl, J. (2018). Getting Digital Tools into Students' and Researchers' Workflows. *Proceedings of the IATUL Conferences*, Paper 6. https://docs.lib.purdue.edu/iatul/2018/infolit/6.

Rihm, S. D., Tan, Y. R., Ang, W., Hofmeister, M., Deng, X., Laksana, M. T., Quek, H. Y., Bai, J., Pascazio, L., Siong, S. C., Akroyd, J., Mosbach, S., & Kraft, M. (2024). The Digital Lab Manager: Automating Research Support. *SLAS Technology, 29*(3), 100135. https://doi.org/10.1016/j.slast.2024.100135.

Schwen, L. O., Kiehl, T.-R., Carvalho, R., Zerbe, N., & Homeyer, A. (2023). Digitisation of Pathology Labs: A Review of Lessons Learned. *Laboratory Investigation, 103*(11), 100244. https://doi.org/10.1016/j.labinv.2023.100244.

Son, J., Narguizian, P., Beltz, D., & Desharnais, R. (2016). Comparing Physical, Virtual, and Hybrid Flipped Labs for General Education Biology. *Online Learning, 20*(3), 228 – 243. https://doi.org/10.24059/olj.v20i3.687.

Stoyanov, A., Gruykin, T., Boyadzhiev, M. & Popovski, V. (2025). Pharmacognostic Analysis and Teachable Machine Automated Identification of Uvae ursi folium, Vitis idaeae folium and Buxi folium. *Journal of Pharmacy & Pharmacognosy Research, 13*(4), 1191 – 1201. https://doi.org/10.56499/jppres24.2231_13.4.1191.

Stoyanov, A. (2024). A Joint Macro and Microscopic Authentication Key for Pharmacognostic Analysis of Croci sativi stigma and its Common Adulterants on the Bulgarian Market. *Natural Science and Advanced Technology Education, 33*(1 – 2), 7 – 16. https://doi.org/10.53656/nat2024-1-2.05.

Vazquez-Briseno, M., Hirata, F., Sanchez-Lopez, J. D., Jimenez-Garcia, E., Navarro-Cota, C., & Nieto-Hipolito, J. I. (2012). Using RFID/NFC and

QR-Code in Mobile Phones to Link the Physical and the Digital World. In I. Deliyannis (Ed.), *Interactive Multimedia* (pp. 219 – 242). https://doi.org/10.5772/37447.

Zhang, M. & Huo, B. (2013). The Impact of Dependence and Trust on Supply Chain Integration. *International Journal of Physical Distribution & Logistics Management, 43*(7), 544 – 563. https://doi.org/10.1108/IJPDLM-10-2011-0171.

Zhang, X., Al-Mekhled, D., & Choate, J. (2021). Are Virtual Physiology Laboratories Effective for Student Learning? A Systematic Review. *Advances in Physiology Education, 45*(3), 467 – 480. https://doi.org/10.1152/advan.00016.2021.

Žurbi, T., & Gregor-Svetec, D. (2024). NFC Tag Awareness and its Visual Implementation on Food Packaging: Case Study in Slovenia. *Applied Sciences, 14*(21), 9933. https://doi.org/10.3390/app14219933.

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