Analysing Student Feedback on the Integration of 3D Printing in the Teaching of Mammography for Radiologic Technologists

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Abstract **–The objective of this study is to assess the suitability of using printed breast models as educational tools for instructing radiographer students on positioning and compression techniques in X-ray mammography. A physical anthropomorphic breast phantom, created with a stereolithography 3D printer based on a computational breast model, served as the main tool in the teaching approach. The practical exercise, conducted in three sessions for first, second, and third-year radiographer students, involved a structured approach in front of the mammography device. A questionnaire assessed participants' opinions on the 3D breast phantom and the exercise's impact on positioning, compression, and mammography device teachings. Among the 83 students surveyed, 52 provided responses, demonstrating a success rate of 71.2% in mastering the exercise utilizing the physical breast phantom. A significant portion of students express the importance of integrating contemporary digital technologies into their academic curriculum, based on the practical experience. The instructor demonstrated thorough preparation and competence in guiding the practical session.**

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The positive experience in this teaching approach strongly encourages future professionals to integrate these new technologies into their daily practice, especially for acquiring skills in compression techniques and breast positioning.

Keywords **– 3D printers, printed breast models, educational phantoms, training in education, radiographers.**

1. Introduction

The radiographer's role in producing high-quality X-ray mammography images is very crucial, with breast positioning standing out as a critical factor ensuring accurate visualization and precise diagnosis of identified lesions [1], [2], [3], [4]. Amongst the main factors that lead to incorrect interpretations of mammography tissue is the improper positioning of the breast [5], [6], which results in "parts of the breast missing" [2], such as the pectoralis muscle [7]. A study by Popli *et al* [8] reveals that nearly 3% of total mammograms exhibited positioning errors. Suboptimal mammogram quality often leads to patient recalls for re-examination, contributing to heightened radiation exposure and causing discomfort to patients [8], [9]. Moreover, patients are subjected to stress and undergo unnecessary additional examinations, such as during magnetic resonance imaging or ultrasound of the breast.

Strøm *et al* [10] have studied the challenges in mammography education as perceived by radiography teachers, mentors, and students. Amongst the main limitations in mammography education were the insufficient study period allocated to this discipline as well as a lack of material resources. These limitations directly impacted the development of students' skills in the field. Since a key factor to significantly influence mammography performance was the breast positioning, this should be prioritized as the central focus in mammography education.

Other challenges are related to handling the pain as well as imaging of women with breast implants [11], [12], and the need for further education. In addition, the study of Meystre *et al* [3] highlighted the necessity for increased training of radiographers, alongside the call for revisions in existing training programs.

To enhance teaching approaches and foster the acquisition of knowledge and skills, updated training programs involve application of anthropomorphic models, produced with 3D printing technologies. They offer possibilities for creation of realistic anatomical phantoms dedicated to teaching students in medical sciences and introduction of 3D printer techniques as disciplines in both BSc and MSc study programs of students in medicine and health care [13], [14]. The source of the 3D printing model is the digital model that may be created from medical simulators or patient medical data [15], [16]. In case of patient data, three-dimensional X-ray diagnostic modalities, magnetic resonance imaging and 3D ultrasound may be exploited. The patient medical images may be stored in different format, such as DICOM format (Digital Imaging and Communication in Medicine format) or jpg, png, raw, tiff, and when anonymized they can be exploited in the design of various anatomical cases. Another approach is by use of medical simulators, which are capable of producing anthropomorphic models. This method offers both flexibility and speed, with the added benefit of eliminating the need for preparation and submission of application to local ethical committee.

Printed realistic medical phantoms are already introduced in the education of medical specialties [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27]. However, these technologies primarily benefit university students in Medicine and Dental Medicine. While 3D printing technologies demonstrate potential to enhance the knowledge and skills of radiographers in X-ray imaging techniques, there is a lack of scientific publications reporting the utilization of 3D printed models for educating radiographers.

The goal of this study is to assess the suitability of using 3D printed breast models in teaching radiographer students through their assessment. The focus is on teaching essential aspects such as positioning and compression techniques for X-ray mammography, as well as providing insights into the mammography device, including its components, functionality, and potential malfunctions. For this purpose, an anthropomorphic breast model is manufactured and a corresponding practical exercise is developed and implemented. Outcomes were measured by processing the data from a dedicated questionnaire.

2. Methodology

The present study is divided into the following main steps: (a) designing of a breast model with dedicated software; (b) processing of the computer model and generation of an STL file; (c) selection of suitable material for 3D printing; (d) 3D printing and model cleaning; (e) assembling the complete breast model; (f) development and implementation of a practical exercise on mammography technique with the physical phantom; and (g) evaluation of the 3D breast model as a training tool.

2.1. Breast Phantom for Radiographer Training

In this study, the physical model of the breast is based on a computational model [28] that can be generated of any size, shape and density. This model is produced by medical simulator *BreastSimulator* [29], comprised of three fundamental modules: (a) creation of computational anthropomorphic breast phantoms based on solid geometry; (b) generation of X-ray images, based on modelled imaging geometries; and (c) visualization of 3D phantoms and X-ray images. The software was employed to generate a comprehensive breast model, composed of 9447 geometrical objects (Fig. 1a). The external shape is defined by the intersection of a semi-ellipsoid and a semi-hyperboloid, with the semi-ellipsoid measuring 7 cm x 6 cm x 10 cm. Within the breast, a glandular tree is formed, originating from the nipple modelled as a semi-ellipsoid. The glandular tree is represented as a series of cylinders, while a mathematical algorithm is utilized to create the lesion [30]. Subsequently, the entire model undergoes processing through a *Matlab* script (available upon request), resulting in an STL file format suitable for printing.

The physical model was created with the stereolithographic (SLA) 3D printer Formlabs Form 3.

The material used for printing the breast phantom was Formlabs resin Flexible 80A V1 (https://formlabs.com/store/materials/flexible-80a-resin/), with elasticity of 80A, when post-cured and density of 1.06 g/cm^3. The model was printed at 100 μm layer thickness with supports and full raft. This included the glandular tree as well. The lesion model was prepared and printed separately with the same resin and settings as the breast model. Furthermore, water absorbing polymer beads with diameter of 8 mm were added to the printed breast phantom. Before inclusion in the breast model, the beads were soaked in fresh water, until no more enlargement of the beads was observed. These beads mimic adipose tissue, introducing breast heterogeneity.

Diluted powder gelatine is incorporated to eliminate air from the breast model.

2.2. Practical Exercise and Student Assessment

Following the model creation, a practical exercise was structured into several steps in front of the mammography device, encompassing a brief machine description, demonstration of the functionality of the mammography equipment, and hands-on experience with the anthropomorphic breast model. The exercise included tasks such as adjusting the mammography machine, placing the breast on the detector plate, changing the X-ray tube angle, positioning the "patient" and applying necessary compression. Students were actively involved in mimicking real-world scenarios, simulating mammographic examinations with considerations for patient comfort, compression force, and machine settings.

The practical exercise took place in three distinct groups comprising students in their first, second, and third year of studying the speciality "Radiologic Technologists" at the Medical College, Medical University – Varna. The exercise was implemented in a dedicated training room at the Medical College in Varna, equipped with a mammography machine without an X-ray tube. Prior to the hands-on session, informative lectures were delivered, providing a comprehensive understanding of the mammography device's description and functioning.

A questionnaire was designed to evaluate the students' opinion regarding the integration of 3D models into their academic curriculum. The questionnaire is arranged in five sections with 13 questions in total, listed in Table 1, and one question has open answer (Q2). The questionnaire is anonymous and voluntary. After the conducted practical training in the room of the mammography machine, the participants were invited to another room where they completed the questionnaire upon their wish, not attended by lecturers.

Table 1. Questionnaire for radiographer students

I	**Past experience**
Q1	Have you previously utilized modern digital technologies during your training? ○ *No.* ○ *Little.* ○ *Yes.*
II	**Experience, evaluation and self-evaluation.**
Q2	According to you, what are the benefits of using the digital technologies compared with the analogue technologies (e.g. film-based mammography)?
Q3	My experience from the current experiment with the phantom – breast model is useful. ○ *Agree.* ○ *Rather Agree.* ○ *Neither Agree, Nor Disagree.* ○ *Rather Disagree.* ○ *Disagree.*
Q4	I coped well with my work with the phantom in the subject of X-ray devices. ○ *Agree.* ○ *Rather Agree.* ○ *Neither Agree, Nor Disagree.* ○ *Rather Disagree.* ○ *Disagree.*
Q5	The use of modern methods based on the digital technologies in the training in X-ray devices is necessary. ○ *Agree.* ○ *Rather Agree.* ○ *Neither Agree, Nor Disagree.* ○ *Rather Disagree.* ○ *Disagree.*
III	**Instructor**
Q6	The attendance of the instructor during the work with the phantom made me worried. ○ *Agree.* ○ *Rather Agree.* ○ *Neither Agree, Nor Disagree.* ○ *Rather Disagree.* ○ *Disagree.*
Q7	The instructor is sufficiently prepared in relation with the work with the printed model, based on the digital one. ○ *Agree.* ○ *Rather Agree.* ○ *Neither Agree, Nor Disagree.* ○ *Rather Disagree.* ○ *Disagree.*
IV	**Use of digital technology in routine work of radiographers**
Q8	After graduation, I would introduce in my practice physical models based on digital models for quality control of x-ray machines. ○ *Agree.* ○ *Rather Agree.* ○ *Neither Agree, Nor Disagree.* ○ *Rather Disagree.* ○ *Disagree.*
Q9	I would financially invest in physical models (e.g. a head model, a child's hand, etc.) to use for optimization of X-ray protocols. ○ *Agree.* ○ *Rather Agree.* ○ *Neither Agree, Nor Disagree.* ○ *Rather Disagree.* ○ *Disagree.*
V	**Other**
10	Gender:
11	Age:

2.3. Statistical Analysis

Statistical analysis was conducted using the R programming language within the RStudio IDE. The study uses categorical variables, and the findings are presented in numerical values and percentages. Spearman's correlation analysis was utilized to explore the relationship between pairs of variables. For items exhibiting significant correlation, a χ^2 test was conducted. A statistically significant result was considered for values of p less than 0.05.

3. Results - Breast Model

Fig 1a shows the created large computational breast model with the software, while the produced physical model is shown in Fig 1b. In this physical model, the breast abnormality is printed by SLA technology and coloured in red for increased visibility. The breast was mounted on a mannequin (Fig 1c) and used in practical training related to breast positioning and applying compression to the breast; thus, mastering these main techniques (Fig 1d).

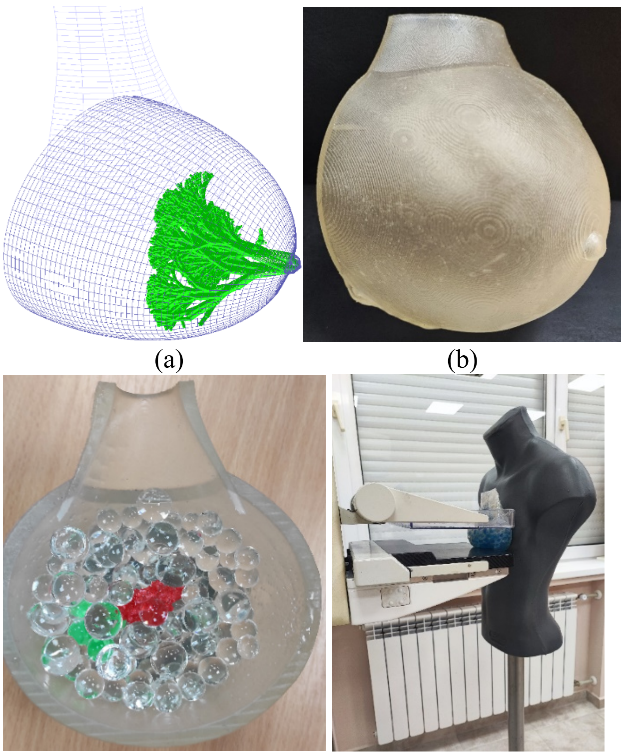

Figure 1. Educational breast model: (a) computational breast model, (b) printed breast model, (c) printed model with tumour, glandular tree and adipose structures, (d) mounted model on the mannequin at a mammography training system (no X-ray tube)

3.1. Results from the Questionnaire

A total of 83 students in the specialty radiologic technologist participated in the training.

From these 52 responded to the questionnaire, of them 38 women (73%) and 14 men (27%), aged between 18 and 33, (80.77% with age in the range 18-24).

The first question addresses the students' previous experience, revealing that they have used modern digital technology during their training. Figure 2 presents a Likert summary of the remaining questions. A substantial majority of the students (98.1%) found their experience with the physical breast phantom to be valuable for their future practice. 71.2% of the students reported that they successfully managed the exercise (Q4), with a significant portion expressing the view that integrating novel digital technology methods into their training is crucial (Q5).

The lecturer's role in teaching mammography examinations was also crucial. Nearly all students were comfortable with the presence of a lecturer during the training (Q6), and all students agreed the lecturer possesses expertise regarding the production of the 3D model and the associated methodology (Q7). Furthermore, 86.5% of the students indicated that they could implement anthropomorphic breast phantoms as quality control tools in their professional work, especially for training of breast compression and positioning on the mammography unit (Q8). Such an approach would be highly advantageous, as the phantom may closely mimic the elasticity and "translucency" to X-rays of actual mammary gland tissues, aspects that require validation in a separate investigation. Hence, most future X-ray technologists intend to use anthropomorphic models in their practice (Q9).

Further, the Spearman correlation analysis is applied on the items from the questionnaire to identify significant patterns. It found a significant moderate positive correlation between (i) the age of the participants and "*the attendance of the instructor during the work with the phantom made me worried*" (r(0.33), $p<0.05$), as well as (ii) "*The use of modern methods based on the digital technologies in the training in X-ray devices is necessary*" and "*I would financially invest in physical models*" (r(0.39), $p<0.05$). The applied Chi-squared test for these two findings is summarized in Tables 2-3, showing a significant association between the categorical items in (i) and (ii), in the questionnaire.

The feedback to the open question Q2 shows that 62% of the students' answers were *"X-ray examinations are easily obtained and with better quality of images"*. The other 38% were distributed between *"Better assimilation of educational material and understanding how X-ray devices work"* (13%), "*Optimised use of X-ray radiation*", (9%), *"Cost effective"* (9%), *"Better preparation for clinical work"* (7%).

Question	Mean (SD)	Agree	Rather Agree	Neither Agree, nor disagree	Rather disagree	Disagree
Q3. My experience from the current experiment with the phantom – breast model is useful.	4.98 (0.14)	98.1%	1.9%	0.0%	0.0%	0.0%
Q4. I coped well with my work with the phantom in the subject of X-ray devices.	4.62 (0.66)	71.2%	19.2%	9.6%	0.0%	0.0%
Q5. The use of modern methods based on the digital technologies in the training in X-ray devices is necessary.	4.83 (0.51)	86.5%	11.5%	0.0%	1.9%	0.0%
Q6. The attendance of the instructor during the work with the phantom made me worried.	1.21 (0.80)	3.8%	0.0%	0.0%	5.8%	90.4%
Q7. The instructor is sufficiently prepared in relation with the work with the printed model, based on the digital one.	5.00 (0.00)	100.0%	0.0%	0.0%	0.0%	0.0%
Q8. After graduation, I would introduce in my practice physical models based on digital models for quality control of x-ray machines.	4.81 (0.53)	86.5%	7.7%	5.8%	0.0%	0.0%
Q9. I would financially invest in physical models (e.g. a head model, a child's hand, etc.) to use for optimization of X-ray protocols.	4.62 (0.69)	71.2%	21.2%	5.8%	1.9%	0.0%

Figure 2. Summary of the results from the questionnaire, presented as a Likert summary

Table 2. Summarised results of $\chi 2$ test and correlation: The influence of the use of modern digital technologies on the possibility to invest in physical models

(Q9) I would financially invest in physical models.	(Q5) The use of modern methods based on the digital technologies in the training in X-ray devices is necessary.						Test $\chi 2$	Correlation. coefficient
	Agree		Rather agree		Rather disagree			
	N	%	N	%	N	%		
Agree	35	78%	2	33%	0	0%	22.77 (p-value 0.001)	0.39 (p-value 0.004)
Rather agree	8	18%	0	0%	0	0%		
Neither agree, nor disagree	1	2%	1	17%	1	100%		
Rather disagree	1	2%	3	50%	0	0%		
Total	45		6		1			

Table 3. Summarised results of $\chi 2$ test and correlation: The impact of instructor attendance during practical work on the students' age

(Q11) Age.	(Q6) The attendance of the instructor during the work with the phantom made me worried.						Test Fisher	Correlation. coefficient
	Agree		Rather agree		Rather disagree			
	N	%	N	%	N	%		
18-24	1	50%	1	33%	40	85%	10.65 (p-value 0.031)	0.33 (p-value 0.016)
25-30	1	50%	2	67%	4	9%		
>30	0	0%	0	0%	3	6%		
Total	2		3		47			

4. Discussion

The utilisation of 3D printed anatomical models in student education may result in enhanced learning outcomes and better understanding of complex anatomical structures [31], [32]. Methods based on 3D printed anatomical models are also appreciated in college education. They greatly assist the integration of students into the clinical environment and handle cases where they need to demonstrate creativity.

It was previously demonstrated that radiographers who had additional practical training in breast positioning for mammography achieve higher positioning quality [7], [33]. Providing additional hands-on training within the curriculum in positioning is one of the most effective approaches for enhancing the quality of mammography positioning, considering that numerous technologists have not received such supplementary training.

It is a fact that until now in Bulgaria, anthropomorphic breast models have not been used in the academic training of radiologic technologist students due to lack of such models. Now, for the first time, they are introduced in their training, potentially contributing to: (i) fostering effective, accurate, and safe practices aligned with legal, ethical, and professional standards; (ii) enhancing proficiency in patient positioning, compression, and comprehensive understanding of mammography device design and functionality, thereby refining skills associated with its operation; (iii) application of anatomical knowledge in breast imaging techniques; and (iv) facilitating active participation in scientific research.

Prior to the exercises, the students expressed that they had not previously engaged in such practical exercises and had only received theoretical instruction on these materials and techniques in lectures. The results from the descriptive statistics, presented in Figure 2, highlight the students' highest awareness of digital medical technologies. This can be attributed to the fact that these students have been involved in training with modern medical imaging devices from the onset of their three-year college program at the University Hospital. This is important in order to decrease the significant knowledge gap in this profession as reported by Seitzman *et al* [34].

Overall, students were very satisfied from their experience with anthropomorphic models, as seen from Figure 2. The breast phantom was printed with transparent resin, which allowed students to visually follow the compression process. This hands-on experience enabled them to observe the compression of distinct breast structures, including the glandular tree, lesions, and adipose tissues. The exercise provided valuable insights into adjusting the compression plate and clarified the significance and necessity of compression in mammography. Students gained a better understanding of the compression plate's role and the reasons for scanning the breast at different positions of the X-ray tube. Therefore, almost 89% of them agreed on the necessity to use new technologies for practical training. A similar level of satisfaction is reported by Valverde *et al*. [35], where more than 95% of the respondents agreed that 3D models aided in improved understanding medical images.

Future radiographers appear convinced about integrating new technologies into their practical work, as indicated by Chi-square test results. This highlights students' acknowledgment of the significance of incorporating digital technology methods into their academic training for optimizing the use of X-ray devices (Table 2).

This has positive impact on their believe that they should financially invest in physical models to be used in their routine clinical tasks (corr. coeff. = 0.39, $p = 0.004$). Nevertheless, in regards to the current state of the country's economic and social development, coupled with the substantial expenses for the necessary technologies (investment for 3D printing device, filaments and resin), just 15% of the responders in this study will have the opportunity to incorporate this innovative technology in their practical work.

The successful implementation of the used technologies heavily relies on the instructors' knowledge and experience with them [37]. Only in this case, the students will acquire the needed knowledge in new technologies and will further implement it in their work. This study showed that the tutor possesses the necessary knowledge, which is attributed to the active involvement in research projects focused on emerging technologies. The presence of the tutor during the exercise also affected positively the work of all students (corr. coeff. = 0.33, $p = 0.016$), Table 3.

The cost of the model was also evaluated. The breast model costs about 55 EUR, not including the labour cost, electricity, deprecation and other consumables needed for post processing such as fresh isopropyl alcohol. Other studies for printing the heart showed a total cost to be 98 USD, which is comparable to the cost of the breast phantom [36]. For the production of these models, an investment in an SLA printer must be made, which in our case has a cost of 4300 EUR. Further, in respect to used materials, one cartridge of the Flexible A80 V1 resin, costs about 240 EUR and it is sufficient for printing approximately four breast models with the tumour formations, like the one shown in Fig. 1. Furthermore, post-processing equipment was used as well, adding to the expenses with about 680 EUR for a machine for washing the models and about 870 EUR more for a post-curing equipment.

The cited costs for 3D printing of the used phantom consider a premium SLA 3D printer with the required consumables and additional equipment. The costs can be considerably reduced by using hobbyist resin 3D printers, with a rough price estimation of around 350 EUR and cheaper resins in the range of 30 to 60 EUR per litre. The quality of the printed models would most likely be reduced, but acceptable. Moreover, equivalents of the post-processing equipment can also be acquired at a lower cost.

The advantages of integrating digital technologies in medicine are well recognized, but it is crucial to acknowledge the ethical concerns that stem with the incorporation of these technologies in the education of medical students [37], [38].

It is important that the tutor conveys these ethical issues to the students at early stage of their education, thus enabling them to grasp and apply the moral standards governing both research and practical clinical practice. Utilizing anthropomorphic models for diagnostic imaging training offers an advantage in addressing this aspect.

5. Conclusion

Exploiting 3D printing technology to create anthropomorphic phantoms proves immensely valuable in enhancing the education of radiologic technologists within medical institutions. Students readily recognize the advantages of incorporating new technologies, as they potentially to reduced procedure time and improved quality in specialized procedures. Overall, radiologic technologists were very satisfied from their experience with the 3D model, as well as the presence of an instructor during the exercise also affected positively the work of all students. The experience with the printed model within this teaching approach seems to convince future radiographers in using them in their routine work, which may open new opportunities for career development and ultimately contribute to the enhanced quality of healthcare services.

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Institutional Review Board Statement

The study received approval from the Ethics Committee of Medical University of Varna: Approval: 123/15/12/2021 and informed consent was obtained from all radiographer students.

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