Enhancing Laboratory Activities in Nuclear Medicine Education

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Hands-on or active learning is important in nuclear medicine education. As more curricula start to require greater standards and as distance education expands, the effective use of laboratories in nuclear medicine education remains important in physics, instrumentation, and imaging but is often overlooked or underutilized. Laboratory exercises are a unique opportunity for nuclear medicine educators to facilitate students' critical thinking and problem-solving skills in a manner that often cannot occur in lectures or during online education. Given the lack of current laboratory tools and publications, there exists a requirement for nuclear medicine educators to develop, enhance, and monitor educational tools for laboratory exercises. Expanding technologies, variations in imaging and measurement systems, and the need to ensure that the taught technology is relevant to nuclear medicine students are issues faced by nuclear medicine educators. This article, based on principles of instructional design, focuses on the components and development of effective and enhanced nuclear medicine laboratories in our current educational environment.

Key Words: education; laboratory activities; instructional design

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The nuclear medicine laboratory is an aspect of education that has been overlooked within recently published materials and resources. Nuclear medicine educators, including both program faculty and clinical instructors, are left to fend for themselves in developing, organizing, and facilitating laboratory activities, along with collecting all the equipment necessary to perform the exercise. A single, comprehensive laboratory manual or guide that includes supplemental laboratory applications has not been published since the appearance of the *Laboratory Manual for Nuclear Medicine Technology* in 1984 (*1*) and *Principles and Practice of Nuclear Medicine* in 1995 (*2*).

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Given this lack of resources, the task of designing laboratory activities for teaching the principles of radiation physics, instrumentation, and imaging can be overwhelming. The advancements in PET/CT, SPECT/CT, cardiac imaging, and automated quality control challenge nuclear medicine educators to keep up with the changing technology and necessary practice competencies. In addition, the variations among different imaging and measurement systems make it almost impossible for a single nuclear medicine faculty to cover all manufacturers and systems. An additional challenge is ensuring that laboratory content is relevant for nuclear medicine technology students. For these reasons, students are often left performing basic quality control procedures, performing outdated or less relevant laboratory exercises, or not performing laboratory exercises at all.

In addition to these challenges, nuclear medicine teachers may not possess educational expertise or realize the basic principles that should be applied during teaching activities to foster effective and efficient learning. This lack of knowledge further affects laboratory activities.

Even with the technologic and teaching challenges, nuclear medicine laboratory activities and exercises are important in the education of future technologists. Faculty should use the laboratory experience to motivate students and assist them to gain deeper knowledge of the difficult physics and instrumentation principles that cannot be effectively taught in the classroom, through a book, or online. The open learning environment of a laboratory encourages students to investigate aspects of nuclear medicine instrumentation, image production, and radiation physics that are often not analyzed in clinical situations because of patient care commitments, lack of available instrumentation time, or constraints on technologists' time.

Nuclear medicine educators have a unique opportunity to expand students' interest in and knowledge of nuclear medicine instrumentation. In the increasingly automated environment, a deeper knowledge and appreciation of the equipment improves patient care and allows one to use the instrumentation most effectively.

LABORATORY DESIGN RESOURCES

Nuclear medicine educators have several solutions available to facilitate and organize interesting, current, and real-world laboratory exercises. Some educators may already have considered these solutions, whereas others may not. Some of these ideas may motivate experienced faculty to revise their practices and enhance what they are already doing.

First, the laboratory exercise should focus on the principle or concept to be taught; the equipment is only a tool to be used during the exercise. Students learn and experience systems from different manufacturers during their clinical education rotations. The laboratory exercise should not necessarily focus on the equipment or try to cover all the different manufacturers. When one is developing the laboratory exercise, maintaining the focus on the concept and principle rather than the specific equipment can be less overwhelming and will allow students to remain focused on the learning goal of the laboratory and not on the operating parameters of a particular piece of equipment.

Second, nuclear medicine faculty can enlist the expertise and support of clinical instructors. This may seem obvious, but educators sometimes overlook technologists who practice in the clinic every day and their numerous years of expertise; these clinicians are valuable resources. Clinical instructors are active nuclear medicine technologists who work in the clinical department and are experts on their respective measurement and camera systems. These individuals experience the equipment and quality control problems directly. Typically, they also have better access to equipment service engineers and manufacturer representatives. Allowing clinical instructors to assist in the design or facilitation of the laboratory exercise demonstrates their value to the program, promotes mentorship between them and students, and provides more real-world laboratory activities based on their experiences.

Medical physics personnel, if available, are also an excellent resource for nuclear medicine program faculty. The physicist or radiation safety officer may be able to clarify difficult radiation safety or physics principles with simple exercises or experiments. These colleagues also have access to resources and equipment that may not be available in the nuclear medicine laboratory.

Nuclear medicine educators must use resources that are available to them and promote the sharing of resources. For instance, the standards documents of the American National Standards Institute (*3*) and National Electrical Manufacturers Association (*4*) provide valuable information for the calibration and use of dose calibrators, scintillation counters, and γ-cameras and for PET quality control. These documents are tools from which educators and students can benefit.

Currently, educator members of the Society of Nuclear Medicine can participate in the educator's community. This community has recently implemented a Web site to promote the sharing of lectures, evaluations, images, and laboratory exercises. This is a great example of how instructors can assist one another in promoting the future of their profession through nuclear medicine education.

By promoting the assistance of clinical instructors and physicists and using currently available resources, one can make laboratory exercises more relevant for the nuclear medicine student. Nuclear medicine educators may find it difficult to strike a balance between the necessary knowledge level and highly in-depth medical physicists' knowledge. However, laboratory exercises should challenge students to become more than "button pushers." Promoting challenging, in-depth understanding of nuclear medicine equipment is important for technologists so they will be able to speak knowledgably with medical physicists and service engineers. Often, a knowledgeable technologist can perform routine quality control and troubleshooting that would cost the department time and money if a physicist or service engineer had to be called.

INSTRUCTIONAL DESIGN AND STRATEGIES

Not only can nuclear medicine educators implement the solutions mentioned, but they also can apply educational theories to design organized, well-structured laboratory exercises. Many times, nuclear medicine educators do not have a background in education or educational theories. Learning and incorporating some basic aspects of instructional design and educational theories can open doors to improved laboratory exercises.

Instructional design is the "systematic and reflective process of communicating principles of learning and instruction into plans for instructional materials, activities, information resources and evaluation" (*5*). There are many different models for instructional design; one need only do a quick search on the Internet to find a great number of resources. One such instructional design model from Smith and Ragan (*5*) includes 3 phases: analysis, strategy, and evaluation. The analysis phase includes determining and specifying the learning context, learners, and learning task. This phase would include developing objectives based on the learning task. The strategy phase involves determining organization, delivery, and management of the content for instruction. An instructor decides the order of content presentation or instructional activities. Finally, the evaluation phase includes assessing the learners' knowledge and assessing the instruction for revision. Another model includes 5 phases: analysis, design, development, implementation, and evaluation (*6*). The content in each phase is similar to the first model but broken down differently.

In addition to the instructional design process, there are many educational theories that can be applied as teaching strategies. For instance, an educator may choose to use simulations, case problems, or problem-based learning (*5*) as different approaches that can be executed in the laboratory setting. Each of these strategies should engage the student in active learning that includes reading, writing, discussing, and problem solving (*7*). The components of learning activities should at minimum include 3 phases: preparation (read assignment, get required materials, and form teams), action (perform core learning actions and submit work), and reflection (consider what was learned and devise ways to apply knowledge or skills) (*8*). Active, engaging, real-world exercises are instructional techniques that encourage students to move from didactic knowledge into a higher thinking order.

LABORATORY DESIGN COMPONENTS

The nuclear medicine educator has the responsibility of effectively using and organizing the laboratory within the curriculum by applying the discussed instructional design models and teaching strategies. An instructionally sound laboratory exercise should consist of objectives, needed equipment, procedure, prelaboratory report, and postlaboratory report (*7*). Published literature has also suggested a prelaboratory stage, an in-laboratory stage, a postlaboratory stage, and a laboratory check as an organizational structure (*9*), and other laboratory structures also exist. Several example laboratory exercises that use a sound instructional design methodology are provided in the Appendix.

Objectives are an important part of any learning event. Learning objectives communicate the focus of the laboratory exercise to the learner and instructor. A laboratory exercise can be an open learning environment. The inclusion of laboratory objectives focuses the students on the goal and what they should learn from the exercise. The laboratory objectives are also a means to communicate the goals of the exercise to clinical instructors if they are facilitating the laboratory exercise or if the students are performing the exercise independently within an online program. The objectives inform students what they are expected to learn from the exercise.

The prelaboratory activity is a structured activity or assignment given to the students before the laboratory exercise. The activity requires students to investigate and review information that is required for the exercise, but the exercise is not discussed explicitly. Examples of such activities include reviewing the half-lives and energies of particular radionuclides, reviewing vocabulary, and reviewing concepts that are discussed in the lecture and will be explored in the laboratory. This prelaboratory activity provides an opportunity for students to review the knowledge they will need for the exercise, allowing them to focus on the laboratory concepts during the exercise and not information they have forgotten or were taught long ago. The prelaboratory activity allows the educator to focus on the exercise instead of on reviewing prior knowledge and information that students can research themselves. The activity encourages students to reflect on the knowledge they have collected and integrate it with the exercise and the concepts they will be exploring.

A complete list of equipment, materials, radionuclides, and instrumentation needed to complete the exercise should also be provided to the students. In addition, step-by-step instructions for the procedure and data collection should be provided. The easier and more straightforward the steps, the more independent the student can be while performing the laboratory exercise. The educator may find it appropriate to assist students by telling them where particular equipment is located (such as in the radiation safety office or the hot lab).

The postlaboratory activity promotes the final synthesis of the researched material, lecture notes, and laboratory exercise. The activity should ask conceptual questions relating directly back to the objectives of the laboratory exercise. Students should be asked to reflect on the observations and data from the laboratory exercise and how the concept relates to nuclear medicine technology in practice. Higher-order questions should be asked, such as those that require differentiating, explaining, relating, and analyzing. These questions will allow the educator to determine whether the students understand the laboratory and concepts.

LABORATORY TOPICS

Laboratory education may be used in the areas of patient care, radiation detection instrumentation, imaging physics, quality control procedures, advanced imaging techniques, and nuclear pharmacy. Examples of potential nuclear medicine laboratory topics include…

- Venipuncture: Students can explore different intravenous injection techniques, including straight injection, butterfly angiocaths, and angiocaths.
- Vital signs: Before clinical rotations, students can practice the procedures for blood pressure assessment, blood glucose assessment, electrocardiography monitoring, and taking other relevant vital signs. Some clinical rotations may even require that such a laboratory or class be completed before the rotation.
- Geiger-Mueller (GM) survey meters and handheld ion chambers: Students can explore the use of each instrument and gain knowledge of the measurement differences between the two (Appendix, example 1).
- Uniformity corrections: Provided the camera has the ability to be adjusted, students can turn off the uniformity, linearity, and energy correction tables individually to deepen understanding of the importance of each and how the correction tables affect image quality (Appendix, example 2).
- Quality control of dose calibrators: Instead of just teaching basic dose calibrator quality control, the laboratory facilitator can alter a precalibration setting and have the students find the problems with the detector (Appendix, example 3).
- SPECT acquisition parameters: Students can experiment with the number of projections and the time per projection to see the impact on SPECT image quality.
- Processing filters: Students can experiment with altering the order, cutoff, and type of filter used to process an image and describe how the images are affected.
- Region-of-interest analysis: Students can practice drawing the region of interest and then compare their quantitative results with those of an experienced technologist. This exercise allows the students to

assess not only their computer analysis skills but also how the region of interest affects the results.

- Pixel sizing: Students can explore pixel-sizing calculations and how they affect quantitative results on the imaging system.
- Image artifacts: Students can purposefully create an artifact on a uniformity or resolution image to see the effect.
- Other quality control measures: Students can investigate the effects of time, total counts acquired, and distance on planar uniformity and resolution. SPECT performance can also be evaluated using center-of-rotation measurements and by imaging and evaluating a SPECT phantom with different time and count parameters. Students can further evaluate the purpose of a "blank scan" for PET quality control and the structure and use of a CT quality control phantom.

In addition to these examples, students may design their own laboratory exercises to explore difficult concepts and the scientific method.

CONCLUSION

The laboratory exercise is an important aspect of the nuclear medicine curriculum and is often overlooked in our advancing profession. Nuclear medicine educators can better promote critical thinking skills by developing more efficient and effective laboratory exercises. These exercises should follow the principles of instructional design and include real-world, active learning activities. The help of clinical instructors and medical physicists should be enlisted, and all current available resources should be incorporated.

APPENDIX

The following 3 examples of nuclear medicine laboratory exercises may be used as teaching tools. Educators may need to adapt these exercises on the basis of available resources and student needs.

EXAMPLE 1: "GM SURVEY METER VERSUS ION CHAMBER"

Laboratory Objectives

- Differentiate the capabilities of a GM survey meter from a handheld ion chamber.
- Explain the unique features and benefits of the GM survey meter and the ion chamber in radiation detection and measurement.
- Demonstrate the proper use of a GM survey meter and ion chamber.

Prelaboratory Activity

- Identify the half-life and γ-constant for ^{99m}Tc-pertechnetate.
- Write out the exposure rate formula.
- Describe the GM survey meter and the ion chamber.
- Differentiate what each detector measures.
- Predict the difference in exposure measurements of a ^{99m}Tc source between the GM survey meter and the ion chamber.

Equipment

- GM survey meter.
- Ion chamber.
- 925 MBq (25 mCi) of ^{99m}Tc-sodium pertechnetate source.
- Calculator.
- Ruler.

Procedure

- Calculate the activity of the ^{99m}Tc-pertechnetate dose in the syringe for the current time.
- Using the exposure rate formula and obtained γ-constant, calculate the expected exposure rate from the ^{99m}Tc-pertechnetate dose at 100 cm.
- Measure and record the exposure of the ^{99m}Tc-pertechnetate dose with the GM survey meter at 100 cm.
- Measure and record the exposure of the ^{99m}Tc-pertechnetate dose with the ion chamber at a distance of 100 cm.

Postlaboratory Activity

- Differentiate the 2 radiation instruments used and their physical characteristics.
- Identify which exposure reading was most consistent with your calculated exposure reading. How do these results compare with your predicted results?
- Explain the exposure reading differences between the GM survey meter and the ion chamber.
- You accidentally drop a contaminated ^{99m}Tc needle on the floor of the hot lab. Explain which survey meter or meters you would choose, and why, to assess the contamination.
- You need to determine whether it is safe to send a ^{131}I thyroid therapy patient home after administering a dose. Explain which survey instrument or instruments you would choose, and why.
- Your hospital is putting in a new PET/CT unit. The room directly behind the PET/CT camera is an administrative office. Explain which survey instrument or instruments you would choose, and why, to determine whether the exposure to the adjacent office is within regulatory guidelines.
- The housekeeping staff accidentally emptied your radioactive waste container into the regular trash. You have to go dumpster-diving to find the radioactive bag. Explain which survey instrument or instruments would you choose, and why.

EXAMPLE 2: "PLANAR CORRECTIONS"

Laboratory Objectives

- Visually assess the characteristics of uniformity, linearity, and energy corrections.
- Differentiate the impact the various corrections have on nuclear medicine image quality.
- Explain the importance of corrections to nuclear medicine image quality.

Prelaboratory Activity

- Define the terms *uniformity, energy,* and *linearity* as related to nuclear medicine images.

Equipment

- γ-Camera on which uniformity, linearity, and energy corrections can be turned off.
- Uniformity sheet source.
- Resolution bar phantom.

Procedure

- Place the uniformity sheet source on the camera.
- Acquire the uniformity.
- Analyze the uniformity quantitative data, and record the uniformity percentage.
- Turn off the uniformity correction.
- Acquire the uniformity.
- Analyze the uniformity quantitative data, and record the uniformity percentage.
- Turn on the uniformity correction, and turn off the linearity correction.
- Acquire the uniformity.
- Analyze the uniformity quantitative data, and record the uniformity percentage.
- Turn on the linearity correction, and turn off the energy correction.
- Acquire the uniformity.
- Analyze the uniformity quantitative data, and record the uniformity percentage.
- Turn off all the corrections.
- Acquire the uniformity.
- Analyze the uniformity quantitative data, and record the uniformity percentage.
- Return all the system corrections to the original status.
- View all uniformity images taken, and describe the image quality for each.
- Take resolution images with each of the corrections turned off.

Postlaboratory Activity

- Describe how the uniformity images and percentages were affected when the uniformity correction table was turned off, when the linearity correction table was turned off, when the energy correction table was turned off, and when all the corrections were turned off.
- Identify the image that had the poorest uniformity, linearity, and resolution quality.
- Differentiate between the quality control procedures and quality control corrections.
- Describe the purpose of a correction table and how it works.
- Explain whether it is important to perform uncorrected quality control procedures, and why.
- Explain when it is necessary to save new uniformity, linearity, or energy correction tables.

EXAMPLE 3: "DOSE CALIBRATOR ACCURACY"

This exercise is more effective if the educator is able to alter one of the calibrated settings for one or two of the radionuclides, allowing students to experience a true problem with the calibrator.

Laboratory Objectives

- Determine the accuracy of the dose calibrator.
- Determine whether the degree of dose calibrator accuracy is acceptable.
- Explain the importance of determining dose calibrator accuracy.

Prelaboratory Activity

- Define the term *accuracy* as it relates to the dose calibrator.
- Identify the necessary reference sources to perform the accuracy determination.
- For the reference sources that are going to be used, record the radionuclide, energy, half-life, activity, and calibration date. Calculate the current activity for each reference source using the decay equation and the information recorded.
- On the basis of the calculated activity, determine the acceptable ranges for the accuracy readings. Refer to the manufacturer's recommendations on percentage error for the readings.
- Decide on any additional recommendations for performing the accuracy determination.

Equipment

- Dose calibrator.
- Sealed reference sources.
- Calculator.

Procedure

- Assay the first reference source on the radionuclide setting. Assay the source using both the calibrated and the manual settings. Repeat the procedure 2 or 3 times, removing the source from the dose calibrator between each assay. Record each of the activity readings, and calculate the average activity for the calibrated setting and the manual setting.

- Repeat the procedure with the second reference source.

Postlaboratory Activity

- Analyze the data by comparing the average assayed activities with the calculated acceptable ranges.
- If any of the data from the exercise should be considered not acceptable, explain why.
- Explain what action should be taken with the dose calibrator, and why. Should the instrument continue to be used? Should it be repaired or replaced?
- If the dose calibrator is working properly, describe occurrences that would require a technologist to repair or replace it.
- Describe the purpose of determining the accuracy of the dose calibrator.
- Explain why it is necessary to apply both the manual dial settings and the calibrated settings when performing the accuracy determination.

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