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The Analog Imaging Visual Cues to Enhance Understanding of Inverse and Direct Square Laws in Digital Imaging.

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Abstract

The Analog Imaging Visual Cues to Enhance

Understanding of Inverse and Direct Square Laws in Digital Imaging.

In this paper the author's goal was to evaluate if the analog based imaging visual cues help radiologic technology students master the inverse and direct square law problem solving skills in digital computed radiography cassette and direct radiography cassetteless radiography. The radiographic conventional analog systems respond with visual hints to increase and decrease in radiographic technique factors unlike digital systems. As a result, the author disabled the brightness and contrast correcting algorithm in digital system allowing it to respond with varying degree of brightness and contrast to changes in distance and mAs. Students in digital imaging evaluate images based on their numeric exposure index and degree of quantum noise. Allowing students to see different amount of brightness and contrast during digital radiographic procedures induced better understanding of the inverse and direct square law concepts. Consequently, students improved their computational fluency when formulating radiographic techniques and gained self-confidence and deeper interest in the more challenging material.

The American Society of Radiologic Technologists' radiography core curriculum and the Joint Review Committee on Education in Radiologic Technology's Standards for an Accredited Educational Program in Radiologic Sciences enunciate that good problem solving and critical thinking skills are absolutely essential in the effective practice of radiologic technology (ASRT, 2011; JRCERT, 2010). In addition to possessing these higher skills, technologists must have a good computational fluency to expediently modify their radiographic technique in response to a changing clinical situation. Unfortunately, the vast majority of the first semester radiologic technology students occupy the lower end of the mathematical skills continuum and a small minority places at the top. This is consistent with the observation that students in the inner- urban classrooms span a broad range of mathematical skills and abilities (Oakley, 2003). The duty of the radiologic educators is to span these gaps in the math skills.

Radiographic Quality in Analog and Digital Imaging

A quality radiographic image accurately represents the anatomic area of interest, and information is well visualized for diagnosis (Fauber, 2012). Radiographic images can be acquired from two different types of image receptors: digital and analog film-screen. The process of creating the image by applying radiation is the same for digital and analog systems, however, processing, and display vary greatly.

The primary factor that affects the amount of brightness or density produced in an image is the amount or quantity of radiation reaching the image receptor. However, the quantity of radiation reaching the image receptor has less pronounced effect on the brightness of a digital image because of image correcting algorithm called autorescaling.

The quantity of radiation reaching an analog film-screen image receptor has a direct effect on the amount of density or darkness produced in a film image. (Bushong, 2016).

Figure 1 shows changes in density in analog system in response to different amount of radiation. Underexposed radiograph has low radiographic density and overexposed radiograph has excessive radiographic density.

Figure 1 Image Density in Analog Imaging

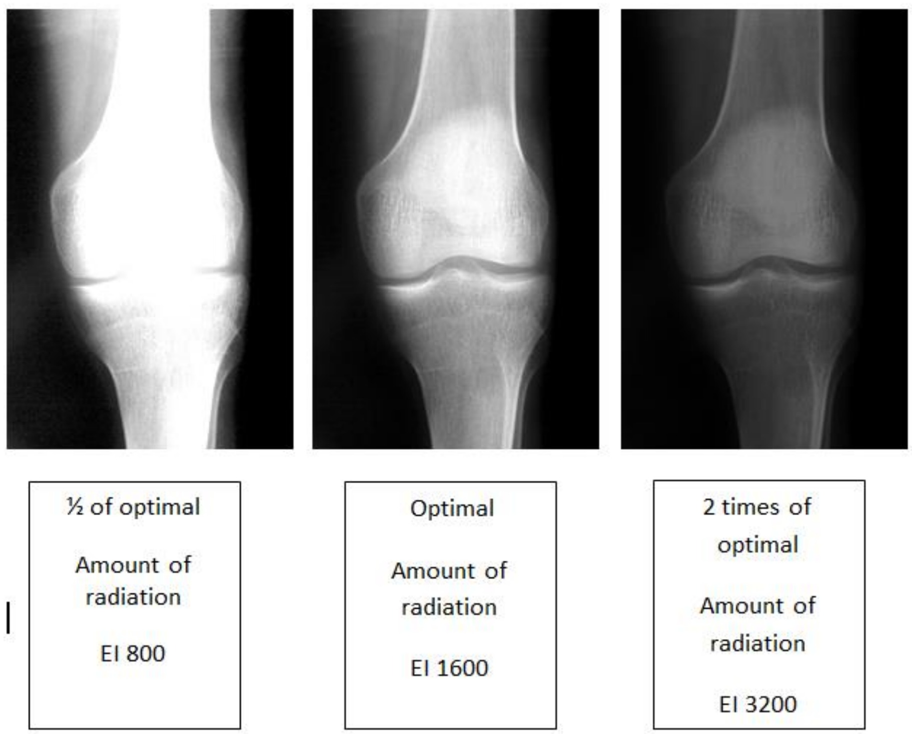
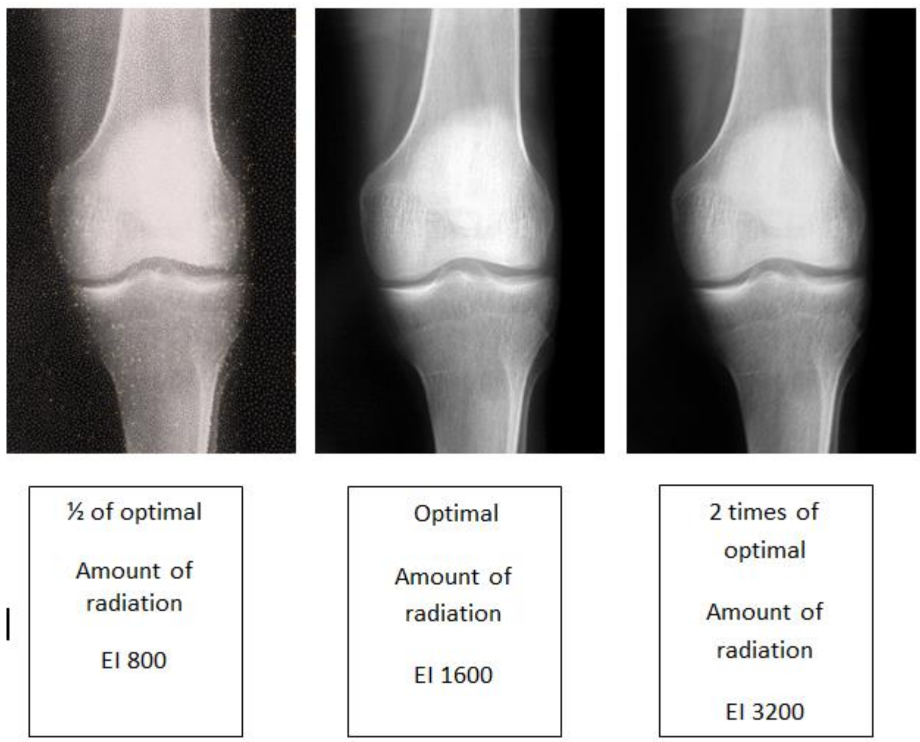


Figure 2 shows three radiographs exposed to different amount of radiation. All radiographs have very similar brightness and contrast because of the autocorrecting algorithm. However, the underexposed radiograph has more quantum noise which manifests itself as graininess. In addition, all images have different exposure indices (EI). Exposure index tells us the amount of radiation that was absorbed by the image receptor.

Figure 2 Image Brightness, Noise and Exposure Index in Digital Imaginning



In digital cassette systems, the exposure index value represents the amount of radiation to the imaging plate, and the values are vendor specific. Fuji and Konica use sensitivity (S) numbers, and the value is inversely related to the amount of radiation to the plate. A 200 S number is equal to 1 mR of exposure to the plate. If the S number increases from 200 to 400, this would indicate a decrease in exposure to the IR by half. Conversely, a decrease in the S number from 200 to 100 would indicate an increase in exposure to the IR by a factor of 2, or doubling of the exposure. Carestream (Kodak) uses exposure index (EI) numbers; the value is directly related to the exposure to the plate, and the changes are logarithmic expressions. For example, a change in EI from 2000 to 2300, a difference of 300, is equal to a factor of 2 and represents twice as much exposure to the plate. Agfa uses log median (lgM) numbers; the value is directly related to exposure to the plate, and changes are also logarithmic expressions. For example, a change in lgM from 2.5 to 2.8, a change of 0.3, is equal to a factor of 2 and represents twice as much exposure to the IR. Optimal ranges of the exposure indices values are vendor specific and vary among the types of procedures, such as abdomen and chest imaging versus extremity imaging (Fauber, et al.)

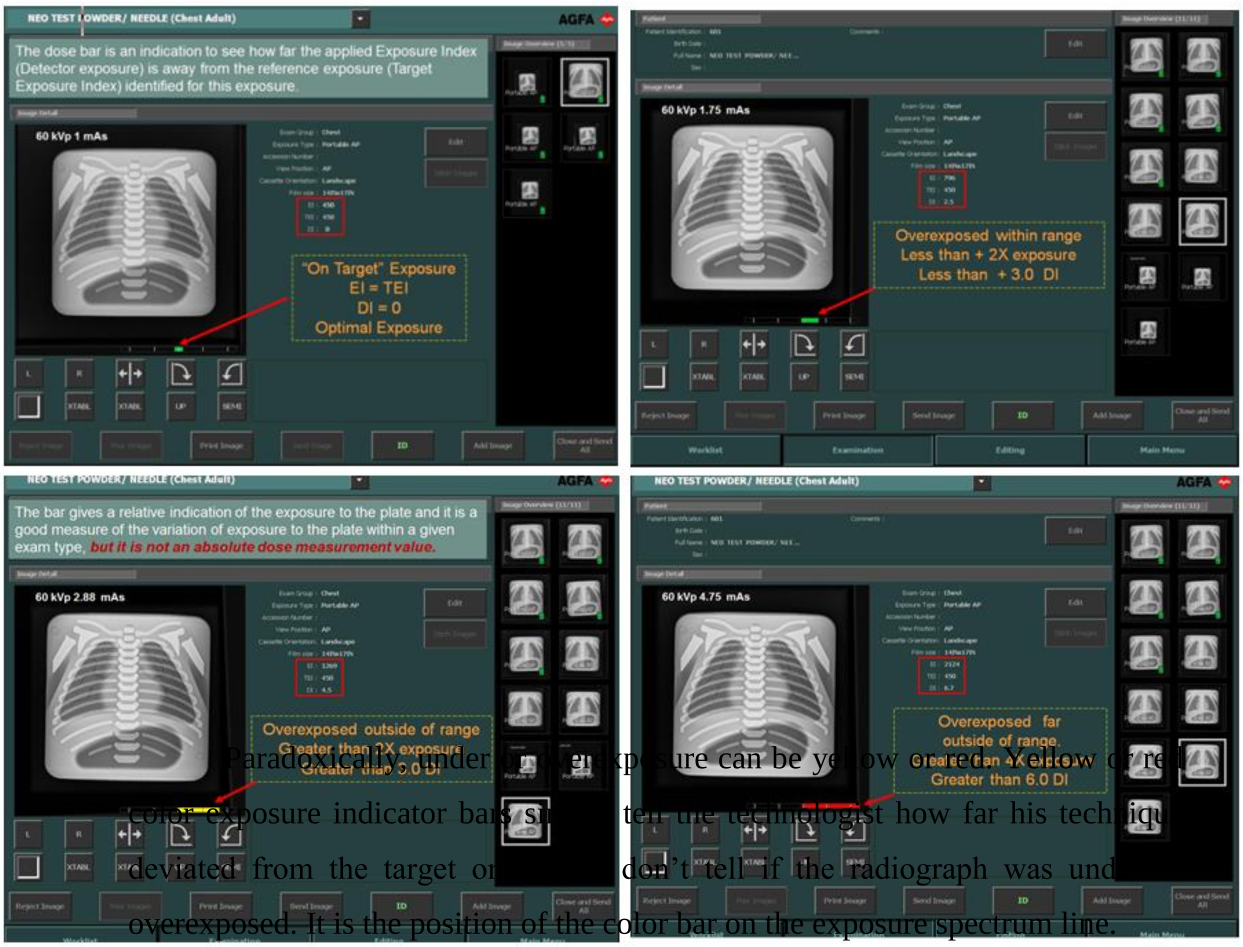
The direct radiography cassette-less systems also use exposure indices that are vendor specific. For example, Agfa use exposure index EI. Agfa EI exposure is different from Care-stream cassette exposure index system. The exposure to an image receptor consists of three clues: target exposure index (TEI), exposure index (EI), and deviation index (DI). Exposure index is linear in relation to detector doseAs exposure to the plate increases, the Exposure Index increases. Target Exposure Index is the reference exposure index for a particular exposure. It can be determined by statistical averaging (50 exposures) and preferred scenario can be pre-set (fixed) by the user. Deviation Index Expresses how far the exposure is away from a reference value and provides a relative indication for under/over exposure three deviation units equals 2x exposure or ½ exposure (+3 or -3) (Gibbs, 2012).

In addition, Agfa introduced exposure color coding system to help technologist evaluate his technical factors. Green color indicates optical radiographic technique, yellow color means caution when patient is overexposed, however, when patient is underexposed it may require repeat. Red color indicates that patient is grossly under or overexposed and repeat radiograph is mandated.

Figure 3 Agfa Exposure Index table

Exposure Index	Deviation Index - DI	Correction Needed
Over Exposed	**4**	**Reduce mAs in half***
800	3	None - Caution
	2	None
	1	None
AIM 400	**0**	**None**
	-1	None
	-2	None
200	-3	Possible Repeat
Under Exposed	**-4**	**Double mAs***

Figure 4 Agfa Exposure Color Coding and Radiographs



Paradoxically, under or overexposure can be yellow or red. Yellow or red color exposure indicator bars simply tell the technologist how far his technique deviated from the target or [illegible] don't tell if the radiograph was under or overexposed. It is the position of the color bar on the exposure spectrum line.

As we can see, Technologists must traverse this labyrinth of different digital exposure factors to generate diagnostic quality images. It must be noted that even the same radiology department has radiographic units that utilize different exposure index system. Every clinical situation has a plethora of patient variables and different exposure indices only add to the complexity of the situation.

Background of the Study

The institution involved in this research project is a radiologic technology program at a two-year public, open admission institution that is part of a city wide system. The total college current student enrollment is 6000 students. Close to 90% of matriculating students enter needing at least one remedial course in reading, writing or mathematics. Consequently, difficulty in completing mathematics courses is a major contributing factor to low graduation rates. The radiologic program enrolls 50 students every fall for the past three years. Students entering the clinical phase of the program must have completed at least seven general education courses with the GPA of at least 3.0. Despite these stringent entrance requirements program has experienced a graduation rate of 54%, which is higher than the overall college graduation rate of 25%, but is lower than the other radiologic technology programs within the same system. Recent accrediting agency evaluation process revealed that passing rate benchmarks for the program were set too low. Deficiencies in math skills were identified as one of the major contributing factors to the low program student retention rate as well. The basic math skill tests administered by the author during the first radiologic Science 1 class during the fall semester of 2016 revealed that vast majority of students were entering the program with the very weak math skills. Consequently, one of the least understood concepts in the radiologic science was the inverse s and direct square laws. The knowledge of these concepts is critical in the radiographic technique formulation and the correct amount of radiation applied to the patient.

The program had had a long history teaching using conventional analog systems. However, recent publication by American Registry of Radiologic Technologist (ARRT, 2016) of the didactic requirements indicated that the knowledge of analog system concepts will no longer be tested on the Radiography Registry Examination. As a result, the faculty decided not to use darkroom and analog processor and not to teach analog imaging anymore.

The purpose of this pilot study was to learn if the students would improve from pre to posttest after conducting Direct Square and Inverse Square Law laboratory exercises. Concretely, the research questions were as follows:

1. Did the laboratory exercises without the correcting algorithm help the students better understand the concept of Inverse Square law?
2. Can the students compensate radiographic technique in response to changes in the distance from the source of radiation to an image receptor utilizing Direct Square law?
3. Can the students identify digital images with the highest amount of quantum noise?
4. Which group of students benefited the most from the laboratory exercises?

Methods

Experiment 1

Inverse Square Law

Students conducted experiment one "Direct Square Law" in the live radiographic lab. Experiment was started with the lab discussion in the form of the soft scaffolding session. The experiment consisted of three parts. Radiographic technique was provided to all students for all six exposures. In part one, instructor exposed ionization chamber at 18" distance and record the reading in the Dosimeter sheet. Students were asked to calculate the exposure intensity at 36" and 72". Furthermore, instructor exposed the dosimeter at those distances and the reading was compared to students' calculated values.

In part two, students exposed natural bone knee phantom at 18", 36", and 72" distance from the target of an x-ray tube to the digital cassette image receptor. However, these three images were processed without brightness and contrast correcting algorithm.

Image two was exposed with correct technical factor and possessed optimal brightness. Image one was too dark because shorter distance and image three was too light and possessed the most quantum noise. Students were able to observe that as the image receptor was moved farther away from the radiation source the image brightness increased.

In part three, the same three exposures were taken like in part two but images were processed using correcting algorithm. No changes in brightness or contrast were observed. However, image taken at 72” distance displayed significant amount of noise.

After the completion of the lab exercises students were instructed to discuss their impressions and findings in their respective lab groups. Finally, instructor engaged students in the soft scaffolding session during which students were asked to explain their findings, impressions, and conclusions.

Experiment 2
Direct Square Law

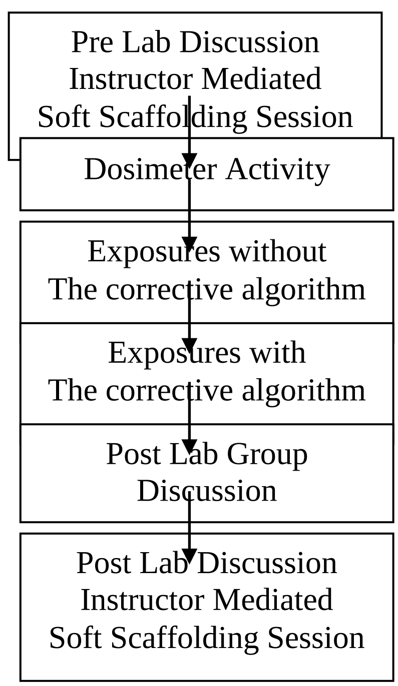
Students conducted experiment one “Direct Square Law” in the live radiographic lab. Experiment was started with the lab discussion in the form of the soft scaffolding session. The experiment consisted of three parts. Radiographic technique was not provided to students for any of the six exposures. In part one, instructor exposed ionization chamber at 18” distance and recorded the reading in the Dosimeter sheet. Students were asked to calculate new technique (mAs) in order to maintain exposure intensity at the image receptor at 36” and 72” distances. Furthermore, instructor exposed the dosimeter with compensated technique at those distances and the reading was compared to students; calculated values.

In part two, students exposed natural bone knee phantom at 18”, 36”, and 72” distance from the target of an x-ray tube to the digital cassette image receptor with compensated technique. However, these three images were processed without brightness and contrast correcting algorithm. All images possessed the same brightness when radiographic technique was compensated utilizing Direct Square Law. Students were able to observe that as the image receptor was moved farther away from the radiation source the image brightness was maintained when mAs was increased.

In part three, the same three exposures were taken like in part two but images were processed using correcting algorithm. No changes in brightness or contrast were observed. The same amount of quantum noise was observed because the radiographic technique was modified in response to a changing distance.

After the completion of the lab exercises students were instructed to discuss their impressions and findings in their respective lab groups. Finally, instructor engaged students in the soft scaffolding session during which students were asked to explain their findings, impressions, and conclusions.

Figure 5
Inverse Square and Direct Law Lab Exercise Learning Schema



Pre- and Post-project Test

The pretest and post test scores ranged from 0 to 100. The pretest was administered during the tenth Radiologic Science 1 class. The post test was administered after 4 weeks later after the completion of the Direct and Inverse Square law laboratory exercises. There were two versions of the tests, with similar items of equivalent difficulty. Versions were counterbalanced across the participants. Initial comparison indicated that the tests were similar in difficulty. The tests included problems that involved the inverse square law and direct square law problems taught in the class and reinforced in the laboratory exercises.

Participants

No comparison group was included in this study. The study involved the convenience sample of radiologic technology students enrolled in Radiologic Science 1 during the fall of 2016 who completed the pre and posttests, Frequency statistics for the respondents (N=48) indicated female population of 44% (n=21) and a male population of 56% (n=27) for the initial pretest. There was an attrition rate of 7 due to the withdrawal from the course. Therefore the withdrawn student's pre test scores were excluded from the evaluation. Final respondent population (N=41) was 49% (n=20) female and 51% (n=21) male.

Results and discussion

For all of the following analysis, students were divided into those who scored above or below 75% on the pre-test and pos-test. The reason to select 75% as the threshold was that American Registry of Radiologic Technologists uses 75% as the minimum passing score. Therefore, students who received above 75% in the pre-test were given group A for example. That group remained the same when examining the post test scores.

The study focused on the performance of the students on two pre and post test questions:

Question 1: *The following radiographic technique 85 kVp and 40 mAs produces an exposure of 200 mR at a source to image receptor distance (SID) of 100 cm. What would the exposure be at an SID of 100 cm if the same technical factors were utilized?*

This question introduced two extra technical factors that are irrelevant to the calculation of the intensity of radiation: kilovoltage peak (kVp) and mAs. These two factors acted as distractors. 40% of students who scored overall below 75% on the pretest answer this question correctly, 77% of students who scored overall above 75% on the pretest answered this question correctly. The improvement on the post test was noted with both groups. 66% of students who scored overall below 75% answered this question correctly and 91% of students who scored overall above 75% answered this question correctly.

Question 2: *If an instrument positioned 100 cm from a point source of radiation is moved 50 cm closer to the source, the radiation intensity will increase or decrease by what factor?*

67% percent of students who scored overall below 75% on the pretest answer this question correctly, 85% of students who scored overall above 75% on the pretest answered this question correctly. The improvement on the post test was noted with both groups. 87% of students who scored overall below 75% answered this question correctly and 94% of students who scored overall above 75% answered this question correctly.

Table 2

Percentage of correct answers on questions 1 and 2

		Question 1	*Question2*
Pre test	Under 75%	40% N=7	67% N= 11
	Over 75%	77% N= 20	85% N=22
Post test	Under 75%	66% N=9	87% N=14
	Over 75%	95% N=22	94% N=24

Figure 5 Percentage of correct answers on question 1

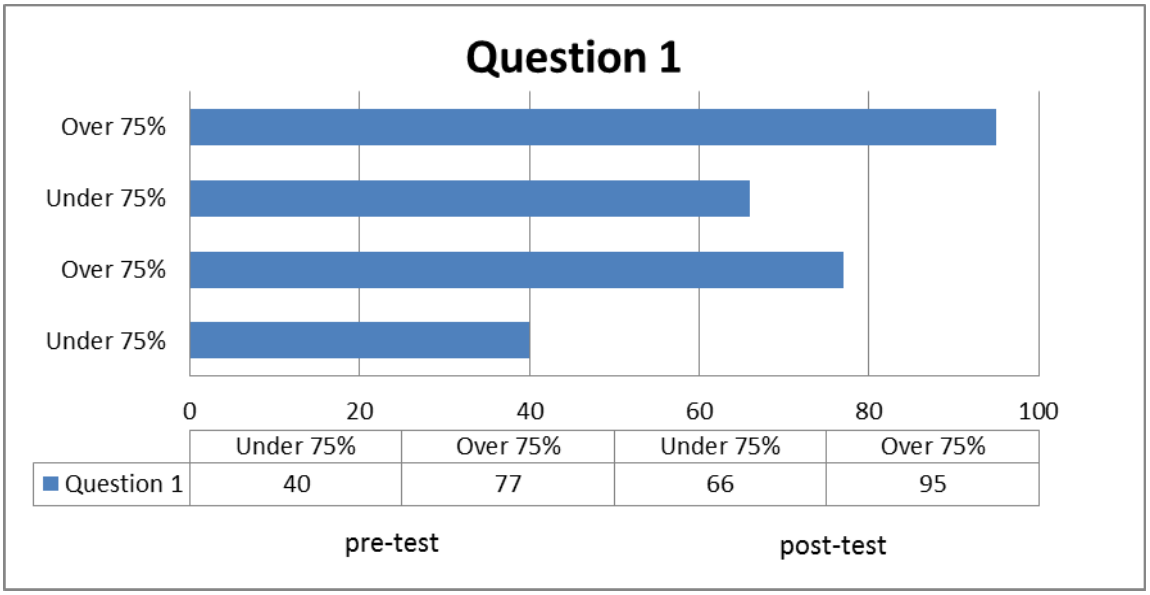


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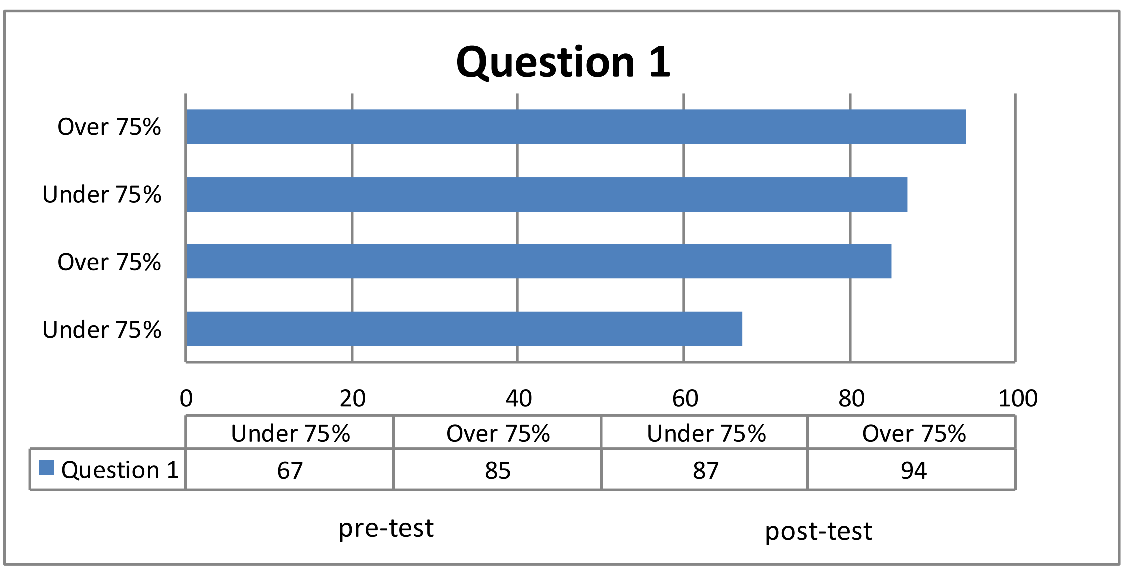
Figure 6 Percentage of correct answers on question 2



Discussion and Conclusion

All students enjoyed conducting the lab experiments. The experiments helped the most the low performing students. They needed that visual stimulation to reach the "eureka" moment. Quantum noise is a confusing concept in digital imaging and many students don't understand its manifestation on the digital radiographic image. Changing image brightness in response to changing distance enabled a lot of students to understand Inverse Square Law. On the other hand, when performing Direct Square law, students understood that technical factor compensation led to maintaining the same image brightness.

"Mathematics is a subject that allows for precise thinking, but when that precise thinking is combined with creativity, openness, visualization, and flexibility, the mathematics comes alive." (Boaler, 2016)

Researchers found that training students through visual representations improved students' math performance significantly, even on numerical math, and that the visual training helped students more than numerical training (Park & Branon, 2013)

"Based upon research outcomes, the effective use of visuals can decrease learning time, improve comprehension, enhance retrieval, and increase retention. In addition, the many testimonials I hear from my students and readers weigh heavily in my mind as support for the benefits of learning through visuals. I hear it often and still I can't hear it enough times . . . by retrieving a visual cue presented on the pages of a book or on the slides of a lecture presentation, a learner is able to accurately retrieve the content associated with the visual." **(**Kouyoumdjian, 2012)

Advantages of using visual cues in digital radiography:

1. Lab exercises provide multisensory stimulation: visual, auditory, tactile and kinesthetic, which help students with different learning styles to better understand difficult concepts.

2. Visual cues are transferred to long term memory where they are indelibly etched and can be later retrieved.

Disadvantages:

1. Requires software engineer to disable image correcting algorithm.
2. Students may erroneously expect that digital image brightness varies in response to radiation exposure.

Limitations

Since a convenience sample was used in this study, generalizations are limited outside of the target institution's radiologic technology program. A larger sample size with a control group could allow more general conclusions about the benefits of the visual cues in digital radiography.

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