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Assessment of radiation learning in Physics-Two Course using the US Guidelines for nuclear engineer and technician careers

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Abstract

The learning of radiation in terms of the radiation absorption law, radiation energy spectrum, muon examination of nuclear waste, etc., have been deployed in a standard Physics-Two course with students in a community college setting. The syllabus extension to include modern topics and radiation content is necessitated due to the offering of a radiation certificate program, a collaboration of our Community College with the Brookhaven National Lab Nuclear Education and Training Program. The radiation certificate program requires two radiation courses to be taught before the fundamental Physics-Two contents. The model-based pedagogy in Physics - Two was designed to complement the phenomenon-based pedagogy in the prior RAD-1 and RAD-2 courses. The Physics-Two syllabus was adjusted with simplification in topics such as acoustic oscillation, magnetic inductor, etc. to provide additional coverage for the contents in quantum modeling, radiation, absorption, muonic technology applications, etc. The grading and assessment pedagogy followed the standard practice, as summarized conveniently by the University of South Carolina. The assessment result showed that the learning of the modern topics was not affected by the simplification of the learning of sound and magnetism topics in classical physics. The skills described by the US Bureau of Labor Statistics Occupation Outlook Handbooks for nuclear engineers and technicians were also evaluated. The nuclear engineer skills in analysis and logical thinking were compared to the nuclear technician skills in computer and critical thinking in the context of Bloom's taxonomy. The recitation content relationship to job description on Indeed.com is discussed.

Introduction

The learning of radiation in terms of the radiation absorption law, radiation energy spectrum, muon examination of nuclear waste, etc., have been deployed in a standard Physics-Two course with students in a community college setting. The syllabus extension to include modern topics and radiation content is necessitated due to the offering of a radiation protection certificate program, a collaboration of our Queensborough Community College (QCC) with the Brookhaven National Lab Nuclear Education and Training Program.

All of the radiation protection program details are listed on the College website with student workshop activities starting Fall 2023 [1]. For instance, Fall 2023 Week 3 covered sources of radiation. nuclear Equations and Week 4 covered the Inverse square law, radiation versus distance and shielding experiments, but without the standard Poisson counting statistics of radiation events in Physics. In Spring 2024, Topics of Particle Generators – Accelerators, Cyclotrons and Synchrotrons are added to strengthen the program. A typical summer internship carries $6,500 plus $600 stipend for books, and transportation, all paid by Brookhaven National Lab (BNL) [2]. There were 6 students accepted into the 2023-2024 BNL Internship Cohort. The BNL funding emphasizes Start: Enroll at Queensborough Community College, Complete AS Degree requirement with radiation protection concentration, and Finish: Apply as a Technician.

Two radiation safety courses are required. The QCC Chemistry Department first course (RAD-101) covers the fundamental knowledge atomic structure; types of radioactive decay; half-life; nuclear reactions and equations; machine production of X rays and radionuclides; interactions between radiation and matter; biological effects and risks of radiation; shielding and atmospheric dispersion, etc., with a math pre-req of algebra. The QCC Chemistry Department second course (RAD-102) covers in-depth knowledge of detector principles, dosimetry, etc. with a co-req of Algebra Physics I Mechanics and Thermodynamics. The Algebra Physics II Electricity-Magnetism & Modern Physics is scheduled after taking RAD 102.

Learning Outcomes

This report addressed the pedagogy of extending the coverage of radiation topics in the Physics II syllabus, with assessment following the US Guidelines, namely the US Bureau of Labor Statistics, for nuclear engineer and technician careers [3, 4]. Two students out of the 2023 cohort (N = 6) already asked about career advancement to nuclear engineer. We anticipate more students will be interested in advancing their careers to engineers after completing two summer technician internships at BNL. Therefore, the key element of Math skill, with ample utilization in Physics II especially being the last course in the Radiation Safety Program schedule, will be practiced throughout the last semester.

The US Guidelines, namely the US Bureau of Labor Statistics, on nuclear engineer and technician career listed the following attributes. Namely, the attributes are Analytical skills. Communication skills. Detail oriented, Logical-thinking skills, Math skills, and Problem-solving skills. All of the above, except Detail oriented, are similar to the leaning outcomes in our RAD-101, RAD102, Physics I, Physics, and the two Math courses in the AS Degree requirement.

By the same Bureau of Labor Statistics, the attributes of a nuclear technician are listed as Communication skills, Computer skills. Critical-thinking skills. Math skills. Mechanical skills, and Monitoring skills. All of the above are similar to the learning outcomes in the lab sections of RAD-101, RAD-102, Physics I and Physics II. The Mechanical skills are fully engaged in the Physics I Mechanics lab exercises.

The extension of Physics II to facilitate the QCC-BNL contract should strengthen Detail oriented among the attributes in a nuclear engineer. The difference between Algebra Physics and Calculus physics mostly lies in the math tool. The Calculus tool enables differential equation inquiry while the algebra tool enables function-solution inquiry. An emphasis on function-solution inquiry beyond arithmetic operation on a given algebra formula will support the development of Detail oriented. The first learning outcome is a mastery of the log plot approach since radiation topic has many exponential functions. The second learning outcome is an understanding of the algebra manipulation steps for a useful function-solution to represent a radiation event.

Pedagogy

The investigation of whether a phenomenon-based pedagogy can match a model-based pedagogy has been published and phenomenon-based learning with a merging of several disciplines has been advocated [5, 6]. The model-based pedagogy in Physics -Two was designed to complement the phenomenon-based pedagogy in RAD-101 and RAD-102 courses without Physics as pre-requisite. The Physics-Two syllabus was adjusted with simplification in some topics such as acoustic oscillation with only the Doppler effect formula in simple application cases, the skipping of ultrasonic device application, the topic of magnetic inductor was limited to simple circuit situation, the topic of AC circuit was limited to formula calculation of impedance, with the skipping of the phasor technique application. The time slots were then spent to provide additional coverage for the contents in radiation physics.

The quantum modeling includes the standing wave pattern for an electron orbit with probability, beyond the energy level formula explanation for absorption and emission, the radiation physics includes the rate equation in difference equation approximation with former calculus, the absorption topics include the fundamental relationship between the real part and the imaginary part of the refractive index in a graphical format without the detailed calculus in the Kramers–Kronig relations in various situations. The muon technology topics include detection principles for fast radiation evets, coincident counting techniques, etc. since we have a muon detection lab with support from Fermi Lab to build a large array of muon detectors to study ultra-energy cosmic rays that generate muon showers when passing through the atmosphere.

The concept of probability is a central pillar in radiation events. The log function description of a radioactive decay using a differential equation model was delivered without the calculus. A decay resulting in the creation of two daughters was used to illustrate the power of the log graph approach with calculus. In fact, a radioactive decay in the creation of three daughters using log graph analysis has been published, with detailed algebra manipulation steps to arrive at a useful function-solution [7].

Our phenomenon-based pedagogy includes the emphasis on the wave properties in the formulas as trigonometry-function-solutions while skipping the Maxwell equations explanation. Our model-based pedagogy includes the emphasis on the Purcell's model of radiation of an accelerating electron with transverse Electric field decay as inverse distance, in contrary to the inverse distance-square in the Coulomb law. On the one hand, the Poisson process in radiation decay measurement gives distribution in the phenomenon-based pedagogy which foster the what- if critical thinking requirement in the nuclear technician career. On the other hand, the theory of the Poisson process in Mathematics-Statistics applies to astronomy, engineering and physics in the model-based pedagogy which foster the analytical skills required in the nuclear engineer career.

The encouragement of students to discuss job opportunities on Indeed.com for about 15 minutes was found to be inspirational, at least to the extent of doing the assignment in a 1-hour session [8].

Assessment

The grading and assessment pedagogy followed the standard practice, as summarized conveniently by the University of South Carolina [9]. The assessment result showed that the learning of the modern topics was not affected by the simplification of the learning of sound and magnetism topics in classical physics.

There were 20% students at “needing improvement”, 40% at “satisfactory”, and 40% at “high pass”, with N = 15, Fall 2023 -Summer 2024. The deliverable was using the log graph approach to extract a decay of 2-daughter creation. The 20% students at “needing improvement” were simply afraid of radiation and not interested, the 40% students at “high pass” were pre-med, pre-dental, and radioactive safety program students. The 40% at “satisfactory” were not interested in radiation safety application and invested their career plans in other fields.

An assessment on the algebra manipulation steps was disappointing with only 10% at “high pass” while 90% at “needing improvement”. The algebra procedure in the derivation of the adiabatic thermodynamics process involving the log function was used to assess if the students understood the log steps in the radiation decay equation to get a useful exponential function-solution.

The nuclear engineer skills in analysis and logical thinking were compared to the nuclear technician skills in computer and critical thinking in the context of Bloom’s taxonomy. The algebra steps were found to be more challenging for most of the studied students while the computer skills and what-if critical thinking in terms of shifting input values by a few percent were found to be at “satisfactory” and “high pass” in terms of computer usage in lab exercises. In other words, the algebra manipulation in the context of physics for getting a useful function-solution as a proxy for the application level in the Bloom’s taxonomy was found to be at a higher cognition level when compared to the understand/remember and analyze/break down levels.

Discussion

We found that a discussion of jobs is good for students during recitation sessions in which they are freely walking inside a lab room, in contrary to the tightly packed classroom in an urban community college setting. Such job awareness seems to encourage them to work more diligently on the assignments.

Most of the radiation safety program students are recruited by the Chemistry Department with student stipend support in the QCC-BNL contract. For consistency, the chemistry perspective on radiation should also be used [10]

BNL contract was given regardless of the pedagogy results whether putting Physics II after RAD-101 and RAD-102 could be workable. In other words, BNL is asking the professors of QCC to deliver a pedagogy that takes all the radiation core courses before taking a second math course and a second physics course. We believe that BNL trusts the research that phenomenon-based pedagogy and model-based pedagogy are equivalent in the training of nuclear technicians. For instance, Open Stax Chemistry book shows decay path in a diagram, not the mechanism [11], and that faculty are asked to fill the missing gap like the Open Stax University Physics book shows differential equation model [12]. The faculty task is not merely adding new topics in Physics II with simplification of some topics in classical physics, it is a novel faculty task to ensure that the skipping of the algebra steps in the classical physics topics can be compensated with a careful design of the teaching of algebra steps in modern physics topics.

The modification of the Physics II to include radiation topics could be further effective when student projects are included as extra credit work for those interested. For instance, the radioactive decay of creating three daughters using algebra 3x3 matrix model has been published and would be suitable to train students interested in the nuclear engineer career [13]. After all a student spending two summers in BNL may go to medical physics, etc., and could forfeit on the technician applications in the QCC Radiation Safety Protection Program supported by BNL.

A faculty member teaching Physics II should be an independent resource to the students and be responsive to students having higher career goals than technician careers. The task of algebra manipulation in the context of learning radiation mechanism in the model-based pedagogy was found to be effective to develop the attributes in the nuclear engineer career listed on the US Bureau of Labor Statistics.

Conclusions

We have concluded that the Model-based pedagogy was useful even when limited to function solution of the differential equation such as radioactive decay solution in the situation of two coupled equations for nuclear engineer. For technician, the formula has numeric content for what- if reasoning. Faculty should support BNL or Government education contracts in spite of the learning schedule that stipulates the learning of all the radiation phenomena in Chemistry before the associated Physics mechanisms in programs for radiation safety protection technicians.

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