Teaching Radiology Physics Interactively with Scientific Notebook Software

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Rationale and Objectives: The goal of this study is to demonstrate how the teaching of radiology physics can be enhanced with the use of interactive scientific notebook software.

Methods: We used the scientific notebook software known as Project Jupyter, which is free, open-source, and available for the Macintosh, Windows, and Linux operating systems.

Results: We have created a scientific notebook that demonstrates multiple interactive teaching modules we have written for our residents using the Jupyter notebook system.

Conclusions: Scientific notebook software allows educators to create teaching modules in a form that combines text, graphics, images, data, interactive calculations, and image analysis within a single document. These notebooks can be used to build interactive teaching modules, which can help explain complex topics in imaging physics to residents.

Key Words: Physics; radiology education; simulation; scientific notebook software.

INTRODUCTION

The American Board of Radiology (ABR) Core Examination assesses knowledge of physics as part of its overall testing in clinical radiology. Physics questions are integrated into each category of this examination (1). Topics emphasized include image quality, artifacts, radiation dose, and patient safety for each modality or subspecialty organ system. Radiology residencies therefore include instruction in physics as part of the residency curriculum. However, imparting an adequate understanding of imaging physics remains a challenging task.

Zhang et al. (2) showed that a hands-on exposure to clinically oriented physics was not only well received by radiology residents but also improved their understanding of the material. It occurred to us that such physical hands-on experiences could be supplemented or possibly even replaced by suitable simulations.

Interactive notebook software is experiencing a rise in popularity in the scientific and engineering communities (3,4), and deserves strong consideration by academic radiologists. This software offers its users an environment for exploration, collaboration, and visualization (5).

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Proprietary scientific notebook software, such as Mathematica (6), Maple (7), and Matlab (8), and open-source notebook software, such as Jupyter (9) and RStudio (10), allow one to create interactive "widgets" that provide an appealing, interactive simulation of some of the physical concepts underlying medical imaging.

We have chosen to use the scientific notebook software known as Project Jupyter, which is free, open-source, and available for the Macintosh, Windows, and Linux operating systems. Jupyter has allowed us to blend together a mixture of explicatory text, images, computations, plots, interactive widgets, and audio files. Students are able to vary imaging parameters and see the results in real time. The goal of this article is to demonstrate some of the radiology physics modules we have created, and to urge other educators to write and share modules of their own.

METHODS

In this article, we focus on the scientific notebook software known as Project Jupyter (9), which is free, open-source, and available for the Macintosh, Windows, and Linux operating systems. Jupyter has its roots in iPython (the "i" is for interactive), which was first developed in 2007 (11). In 2014, the notebook and other parts of the project were spun off into Project Jupyter, which aims to make iPython more compatible with other languages. The name Jupyter is actually a portmanteau of Julia, Python, and R, three of the first languages supported by this project. We did not write Jupyter, but are enthusiastic users of the software.

Using Jupyter

We have described in detail how to install and run Jupyter notebooks elsewhere (12). We will very briefly recapitulate this information here. To use Jupyter, one must access a Jupyter server using a web browser. This Jupyter server can be located remotely somewhere on the Internet, or locally, on one's own computer.

The easiest way to test-drive Jupyter is via the remote Project Jupyter server at https://try.jupyter.org. This temporary notebook service allows one to experience Jupyter without having to first install and configure it on one's own computer.

However, the optimal way to use Jupyter is install and run it on one's own computer. This installation is relatively simple if chooses one of the following systems:

1. Enthought Canopy (https://www.enthought.com)
2. Anaconda Python (https://www.continuum.io/)

Both the Enthought and the Anaconda systems offer free versions. Both systems install not only the Jupyter notebook software but also a complete distribution of the scientific Python (SciPy) (13) and numerical Python (NumPy) (14) libraries. Of the two systems, we currently prefer the Anaconda package, which we have found to be easier to install and update, especially for newcomers to Jupyter.

Jupyter notebooks can contain text, tables, equations, or Python code. Text can be formatted using Markdown, a lightweight formatting language (15,16). Equations and other mathematical expressions can be entered into a notebook cell using LaTeX notation (17). Any Jupyter cell can be "evaluated" by selecting that cell and then hitting *shift-enter* on one's keyboard. For a cell containing text, tables, or equations, that cell will be typeset on the screen. When a cell contains a short computer program segment in Python (or some other language), hitting *shift-enter* will run that segment.

RESULTS

We have created a number of interactive Jupyter modules that teach concepts of radiology physics. Sample modules demonstrate important principles of nuclear medicine, ultrasound, radiography, and magnetic resonance (MR) imaging. These modules are contained in a single Jupyter notebook file which can be downloaded from our server (http://uwmsk.org/jupyter/). This notebook can also be viewed there as a static webpage.

Nuclear Medicine

Module 1. Simple Radioactive Decay

When a parent radionuclide decays to a daughter radionuclide, the decay follows an exponential form, as shown in Equation 1:

$$A(t) = A_0 e^{-\lambda t}, \tag{1}$$

where A_0 is the initial activity, t is time, and λ is the decay constant—the probability that a radioatom will decay per unit time (18). This decay constant is related to the isotope's half-life $\left(t_{\frac{1}{2}}\right)$—the time when 50% of the radioatoms present will have decayed—as shown in Equation 2:

$$t_{\frac{1}{2}} = \frac{ln(2)}{\lambda}. \tag{2}$$

Half-life has direct implications in nuclear medicine imaging, radiation therapy, and radiation safety. For example, the half-life can make it relatively simple to calculate how much of a radioisotope will be left after a given time. For example, technetium-99m (^{99m}Tc) has a half-life of about 6 hours. Therefore, after 24 hours, the remaining amount of ^{99m}Tc will be $1/2 \times 1/2 \times 1/2 \times 1/2$ or 1/16 of the original amount.

We used the decay equation to write an interactive teaching widget in Jupyter. In this simple widget, one can vary the half-life using a control slider and immediately see the effect on the decay curve (Fig 1).

Module 2. Technetium Generator Simulation

One of the more common radioisotopes used in nuclear medicine is the metastable isotope ^{99m}Tc.

^{99m}Tc has a half-life of only 6 hours, which is very convenient for many diagnostic procedures. However, it is very inconvenient to transport short half-life isotopes.

Fortunately, an isotope of molybdenum (^{99}Mo) has a much longer half-life (66 hours) and decays to ^{99m}Tc, which, in turn, decays to ^{99m}Tc (half-life = 211,000 years). The relatively long half-life of ^{99}Mo makes it much more convenient for transport from the reactor where it is made to the nuclear medicine department where it will be used clinically. The decay scheme for ^{99}Mo is shown in Equation 3:

$$^{99}Mo \xrightarrow{\lambda_A} {}^{99m}Tc \xrightarrow{\lambda_B} {}^{99}Tc \tag{3}$$

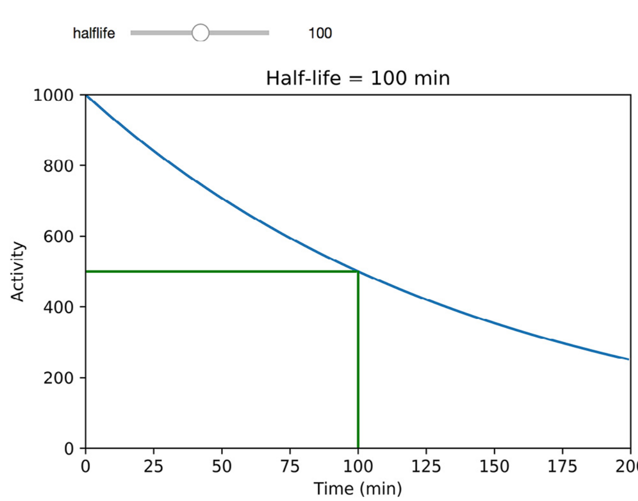

Figure 1. Jupyter interactive widget for simple radioactive decay.