Title: A Smarter Course: Filling the Gap in Training Safeguards Experts

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Abstract:

Pacific Northwest National Laboratory (PNNL) has offered and maintained an introductory course on nonproliferation and international safeguards for students and early career professionals for the past decade. In 2020, PNNL transitioned the course to virtual facilitation as a result of the COVID-19 pandemic. The team at PNNL utilized the transition period as an opportunity to change the curriculum from an introductory to an intermediate course. This transition changed the target audience to early and mid-career professionals who wish to expand their understanding of nonproliferation and international safeguards concepts.

The new International Atomic Energy Agency (IAEA) Safeguards: From Theory to Practice course includes several lectures, demonstrations, and exercises presented by experts on topics ranging from the nuclear fuel cycle to in-field verification activities. The PNNL team also developed technical activities to compliment the more advanced level of curriculum. These improved virtual training activities used information from a PNNL-developed State File for a Pacific Northwest-centric, faux country called "Flumina." For the past two years, the course creators utilized new virtual collaboration tools (i.e., Mural) to conduct various exercises. Such virtual tools were critical to refocusing the course topics on the implementation and process of IAEA safeguards.

Exercises featured in the course included:

- A nuclear fuel cycle mapping exercise where students identified relevant information from the draft Flumina State Evaluation report to complete a fuel cycle diagram, map facilities, and track nuclear material flow
- A design information verification exercise—including virtual layouts and walkthroughs of facilities—where students reviewed operator declarations, verified facility design and layout, and analyzed the data to confirm accuracy of the declaration
- A facility-level safeguards implementation exercise where students performed a diversion pathway analysis to analyze proliferation/diversion pathways, establish and prioritize technical objectives, identify key safeguards measures/activities for facility-level implementation, and illustrate how containment/surveillance measures help verify operator records and systems
- A State Evaluation exercise where students learned the techniques the IAEA uses to evaluate a State's nuclear fuel cycle and implement safeguards

Introduction:

Since its inception in 2008, the National Nuclear Security Administration's Office of International Nuclear Safeguards Human Capital Development (HCD) subprogram has supported several initiatives to develop and maintain a cadre of new U.S. nuclear safeguards experts to replace the many retiring professionals. In the early years of the program, HCD emphasized the attraction and education of future safeguards professionals through activities like university curriculum development and internships to address the accelerating attrition rate.

PNNL has offered and maintained an introductory course on nonproliferation and international safeguards for students and early career professionals for the past decade. The objective of the course was to provide participants with a fundamental understanding of the nuclear fuel cycle, the nuclear nonproliferation regime, international safeguards agreements, and verification mechanisms through lectures, hands-on activities, and facility tours.

Currently, there are a variety of fundamental and advanced safeguards courses available to U.S.-based nonproliferation professionals. However, there are few mechanisms to develop competencies which bridge the gap between fundamental and in-depth mastery of safeguards-related skillsets.

In 2020, PNNL transitioned its introductory course to a virtual setting during the COVID-19 pandemic. The team at PNNL identified this change as an opportunity to redevelop the curriculum from an introductory to an intermediate course to fill the gap in development opportunities. The target audience for the course was refocused from graduate students and early career professionals to early and mid-career professionals and those transitioning into the international safeguards field.

The challenges associated with this effort included designing a curriculum that:

- Targeted content to the right depth for a new audience
- Promoted engagement for virtual audiences
- Could be easily adapted for varied proficiency of the audience

To address these challenges, the team developed several solutions:

- Competency matrix-based curriculum development and planning
- Leveraging collaboration software and tools in the development of group-based virtual exercises
- Multi-tiered exercises and content complexity to adapt for a range of student engagement or background

Development of the 'New' Course:

Solution #1: A detailed competency-based approach matrixed with Bloom's taxonomy.

The systematic approach to training requires a framework for understanding the needs of a workforce[1]. PNNL developed a list of topical areas which are broadly applicable as international safeguards expertise areas. The topical areas (with focus areas in bold) identified were:

- Elements of the International Safeguards Regime
- International safeguards legal framework and authorities
- Nuclear Fuel Cycle
- **Implementation of International Safeguards**
- Nuclear Material Accountancy
- **Inspections**
- **Complementary Access**
- State Systems of Accounting and Control of Nuclear Materials
- **Technical methodologies, techniques, and instrumentation**
- Radiation Protection and Worker Health and Safety
- Nuclear export control

By detailing concepts within each topical area, a list of safeguards specific expertise (SSE) was gathered. Bloom's taxonomy[2] was coupled to the list of SSE to provide the framework to assess the course's current curriculum. This framework, or matrix, provided a means to assess the level of complexity and specificity of current topics in the course curriculum through a structured methodology.

For example, the course designers were able to review individual lectures, identify topical areas and individual concepts, and fill in the matrix at the appropriate learning level to develop an integrated course competency matrix. By comparing the content to the SSE (listed in the matrix), gaps in content were identified and an overall picture of the course's complexity and content level emerged.

This framework then allowed for the establishment of the Course Goals, Course Objectives, Topics, Topical Learning Objectives, and the identification of Concepts for the course redesign effort. Topical focus areas (identified in bold above) were chosen and the course goals were developed. Utilizing the educational taxonomy, the level of learning for each SSE would be specified to create the course learning objectives.

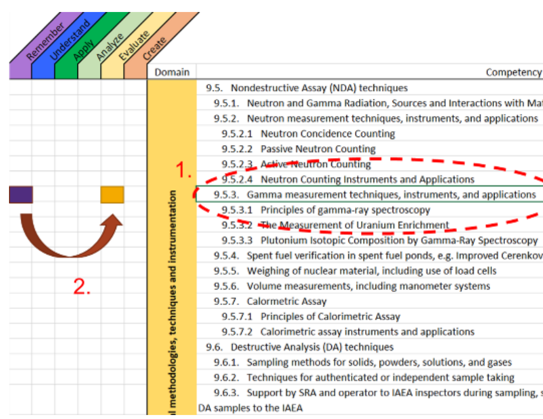

Figure 1: Competency Matrix developed by PNNL

This pedagogic approach ensured that each concept taught during the course was directly tied to a learning objective, which ultimately supported the

[1] Ticevic, Sabina, et al. The Systematic Approach to Training: Analysis and Evaluation in the Department of Safeguards. No. IAEA-CN--220. 2015.

[2] Bloom, B. S.; Engelhart, M. D.; Furst, E. J.; Hill, W. H.; Krathwohl, D. R. (1956). Taxonomy of educational objectives: The classification of educational goals. Vol. Handbook I: Cognitive domain. New York: David McKay Company.

Course Objectives and Course Goals. It helped ensure that the appropriate resources and instructional type were allocated to each concept based on their relationship with the learning objectives and avoided the overemphasis of any one topic, learning objective, or concept. Detailing SMART goals (Specific, Measurable/Observable, Attainable, Relevant, Targeted)[3] developed from the educational taxonomy created meaningful learning objectives.

Solution #2: Utilizing interactive tools to drive engagement and teaming.

Virtual presenting offers several challenges which needed to be overcome including the lack of (or limited) audiovisual feedback from the audience, increased barriers to audience interactivity, and increased difficulty maintaining audience engagement (i.e., a more distractive environment).

The transition to a virtual meeting format required the implementation of new teaching methods not previously used by course instructors to help overcome some of these challenges. The use of teaming and engagement tools were not unique to virtual training, but the PNNL course team found that *how* they were used could increase teaming and participant engagement.

Zoom (Zoom Video Communications, Inc.) was the video conferencing and collaboration tool used by the PNNL team to host the virtual training course. Using 'breakout rooms' during exercises and discussion periods allowed course facilitators to split the Zoom meeting into several smaller meetings where teams of 3-5 students could work and engage. Course facilitators answered questions and supported the exercises and discussions in each small group which allowed for more interactions where every student was engaged.

Zoom's polling and chat features were used to reduce the burden on lecturers and increase audience participation. The polling feature allowed course facilitators to create single-choice or multiple-choice polling questions for the meeting. Course designers worked with lecturers to add in polling questions to check students' background knowledge on subjects beforehand, increase participation, and ask knowledge check questions to gauge the success of the lesson in meeting learning objectives.

The course designers aimed to reduce the strain on lecturers (while increasing interactivity with students) by meeting with them prior to the week of the course to check audio and visual setups, verify internet connections, and practice presenting slides and using polling questions. The day-of responsibilities of the lecturer were limited to providing their presentation. The primary course facilitator monitored the meeting chat for questions from students and raised those which could not be answered in the chat box. Multiple facilitators answered questions and provided supplemental course material through in-chat links, content, discussion, and context. The lecturers were able to focus on their presentation and students were provided with near-constant access to questions and supporting materials.

Mural (Tactivos, Inc. d/b/a Mural) is a visual collaboration web site aimed at providing tools and resources—a shared whiteboard where images, 'sticky notes' and drawings were added by students and edited by their breakout group—for effective collaboration. PNNL course designers developed templates for each exercise that acted as virtual worksheets for each team to use in their breakout

[3] Doran, G. T. 1981. "There's a S.M.A.R.T. Way to Write Management's Goals and Objectives. Management Review." AMA Forum 35-36.

groups. For example, during the Design Information Verification exercise, students reviewed operator declarations, verified facility design and layout through a virtual tour of Hanford B-Reactor on Google Maps, and analyzed their data to confirm the accuracy of the declaration. The Mural worksheet template developed for the exercise included the facility map, instructions, and icons for students to copy/paste. The breakout groups used the Mural whiteboard as a central information-gathering and collaboration space as they teamed up to tour the facility, verify design and construction, and take photos of essential equipment.

A key feature of using the Mural platform was the ability to efficiently assess and adapt the exercise materials and logistics with minimal effort. During the design of the course, facilitators were able to quickly design, implement, test, and adapt the material, layouts, and instructions of the Mural templates to review new ideas. This led to rapid progress in the maturity of the exercises with minimal time investment. Even as the course transitions back to in-person offerings, this tool is envisaged to be a key resource for the design of future instructional materials.

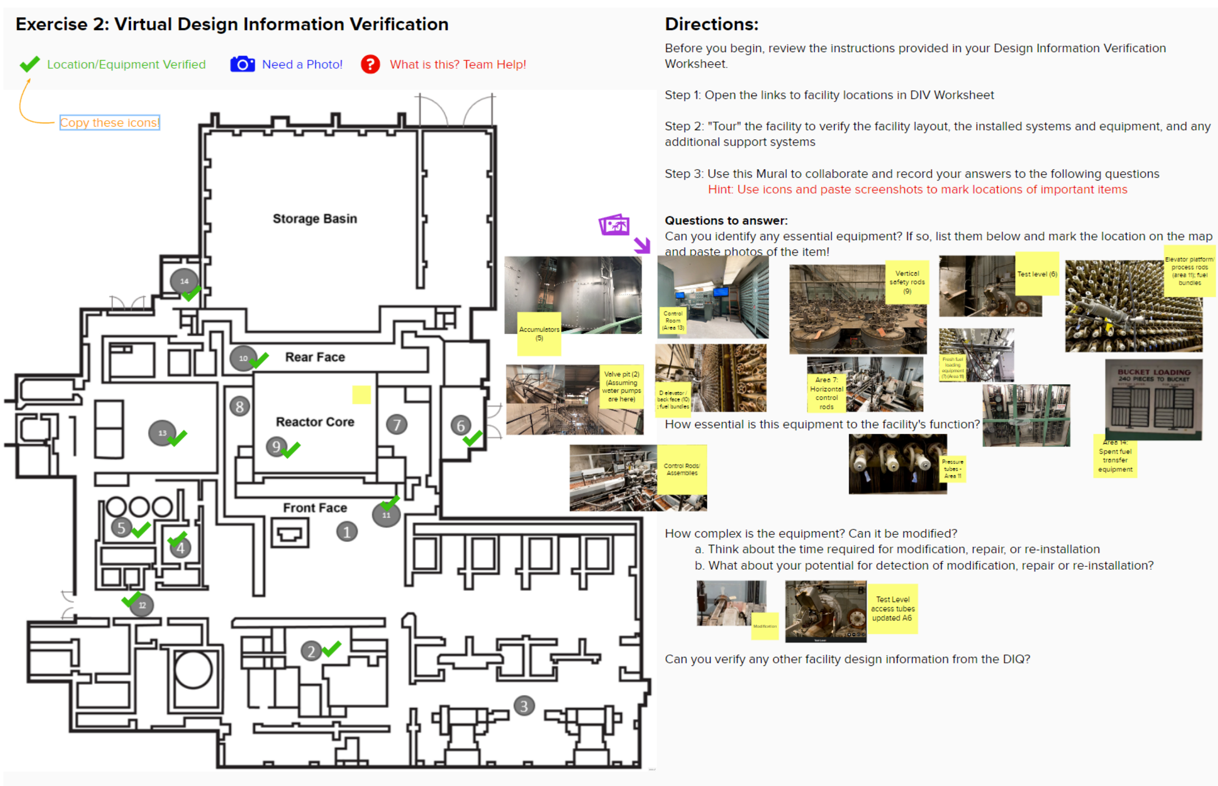

Figure 2: Mural collaboration software being used for a virtual Design Information Verification exercise

Solution #3: The course expanded on the applied safeguards topics which incorporated tiered-difficulty technical exercises to compliment the more advanced level of curriculum.

Ensuring that a training course's audience has a uniform background, education, and experience level is not only impossible but undesirable. The material developed for a training course needs to be adaptable to allow for these variations, including levels of student engagement. During PNNL's course restructuring, the exercises were identified as the best option to design in an adaptable level of complexity to the course. Exercises featured in the course included:

- A nuclear fuel cycle mapping exercise where students identified relevant fuel cycle information from a draft State Evaluation report to complete a fuel cycle diagram, map facilities, and track nuclear material flow
- A design information verification exercise where students reviewed operator declarations, verified facility design and layout, and analyzed the data to confirm accuracy of the declaration
- A facility-level safeguards implementation exercise where students performed a diversion pathway analysis, established and prioritized technical objectives, and identified key safeguards measures/activities
- A State Evaluation exercise where students evaluated a State's relevant safeguards information, performed acquisition path and consistency analyses, and ultimately drew a safeguards conclusion

Each exercise offered an opportunity to integrate tiered "complexity-by-design" into the content and structure of the exercise. For example, the improved virtual training activities include the PNNL-developed State File information for a Pacific Northwest-centric, faux country called "Flumina." In the Design Information Verification exercise, the material provided to the students allowed a wide range of engagement, including touring the facility to verify the layout, taking screenshots of essential equipment or reactor components, and identifying and verifying design details listed in the Design Information Questionnaire (e.g., piping and instrumentation diagrams).

Lessons Learned:

Combining expertise with Bloom's taxonomy created a competency matrix used to assess and understand not only the "what," but the "level of knowledge" the training course needed to address. This tool can be used to assess the content of courses, identify topical areas, and determine the level of detail needed to meet course objectives. Additionally, the tool can help the nonproliferation community at PNNL better assess competency gaps within the laboratory workforce.

New virtual collaboration tools were effectively used to increase engagement. Students and lecturers noted the versatility of Mural (the virtual collaboration tool used to facilitate the course's exercises) and acknowledged the benefits of using such a tool to promote collaboration within breakout groups. The lessons learned from the development and running of exercises in Mural allowed for the course development team to quickly refine exercise concepts and logistics in preparation for the 2023 in-person course with minimal additional preparation.

The intricacy of the course's exercises proved difficult to conduct in a virtual setting. Although Mural proved to be an invaluable asset, information management (e.g., document shuffling on screens while trying to participate in Mural breakout sessions) was difficult. Each iteration of the course and exercises reduced the volume and complexity of the supplemental material given to students.

Outcome:

Students noted the uniqueness of the course and the wealth of knowledge gained from participation. The primary outcome of this course was to provide a new cadre of early and mid-career professionals with the ability to contribute more effectively to safeguards projects and activities. While engagement in a virtual environment was challenging, students showed an increase in engagement in each iteration of the virtual course as teaching techniques, content, and exercises were refined. The exercises built on each other throughout the week, expanding student perspectives on work produced the day before. Survey scores throughout the week mirrored this approach, with participants finding the first couple days difficult (especially within the time constraints), but scores and comments on their understanding and interest went up significantly for the remaining few days.

References:

1. Ticevic, Sabina, et al. The Systematic Approach to Training: Analysis and Evaluation in the Department of Safeguards. No. IAEA-CN--220. 2015.
2. Bloom, Benjamin S., and David R. Krathwohl. Taxonomy of educational objectives: The classification of educational goals. Book 1, Cognitive domain. longman, 2020.
3. Doran, George T. "There’s a SMART way to write management’s goals and objectives." Management review 70.11 (1981): 35-36.
4. Englert, Matthias. "Proceedings of the INMM & ESARDA Joint Virtual Annual Meeting August 23-26 & August 30-September 1, 2021." (2021).