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Title: The Gulf Nuclear Energy Infrastructure Institute: A Multidisciplinary Educational Approach for Integrated Nuclear Energy Safety, Security and Safeguards in the Middle East

Abstract
The Gulf Nuclear Energy Infrastructure Institute (GNEII) at Khalifa University of Science and Technology was created as a regional institute offering education, research and technical services to support nuclear energy safety, security and safeguards (3S) objectives. A mixed methods approach—using the (1) *Course Evaluation*, (2) *GNEII Alumni Survey,* (3) *Capstone Project* and, (4) *GNEII-Related Literature* data sets—was used to evaluate the effect of implementing this multidisciplinary '3S' educational program and the broader impact of the associated '3S' multidisciplinary institute on nuclear energy human resource development. Data sets (1), (2) and (3) illustrate how well GNEII implemented this novel 3S curriculum and resulted in successful knowledge transfer. Data sets (2), (3) and (4) illustrate how well GNEII's impact has positively influenced professional workplace behaviors and the institute's broader reputation to support responsible nuclear energy program education. GNEII demonstrates one option for successfully providing a multidisciplinary, 3S curriculum to support broader nuclear infrastructure and human resource development aims.

NOTE: This paper is a revised and expanded version of a paper entitled *Evaluating the Educational Impact of the Gulf Nuclear Energy Infrastructure Institute (GNEII)'s Novel 3S Approach* presented at the 58th Annual Meeting of the Institute for Nuclear Materials Management in Indian Wells, CA, USA July 16-20, 2017.

Keywords
Multidisciplinary education, Nuclear infrastructure development, Nuclear human resource development, Nuclear safety, Nuclear security, Nuclear safeguards, 3S education

Author Biographies
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2011 to 2017, and participating in early GNEII Steering Committee meetings. Philip A. Beeley is the nuclear engineering department chair at Khalifa University for Science and Technology and is the Founding Director for GNEII. Saeed Al-Ameri is a faculty member in the nuclear engineering department at Khalifa University of Science and Technology and have served as the GNEII Manager since 2017.

Introduction

The late 2000s and early 2010s saw an increased global interest in nuclear energy, primarily driven by a desire for improved living and social standards, energy security, and climate change mitigation. Many of the regions expressing a strong interest in nuclear energy programs—such as the Gulf region—lacked the necessary human infrastructure to support such programs. Here, human infrastructure incorporates two key aspects. First, it includes having adequate numbers of individuals available to work in nuclear-energy-related government and industry positions. Second, it also includes ensuring such individuals have the appropriate level of education, training, experience, and knowledge across a range of responsibilities within nuclear power programs. In addition, the new nuclear energy program in the United Arab Emirates (UAE) demonstrated a need to address the lack of *indigenous* human infrastructure capabilities available to support growing regional interest in nuclear energy.[1]

Addressing this gap in nuclear energy human infrastructure development posed two unique challenges. The first related to limited knowledge and experience in nuclear energy programs existing in Gulf-region states. The second related to the breadth of safety, security and non-proliferation (or, safeguards) concerns unique to nuclear energy programs. What resulted was a lack of appreciation across these varying concerns, as demonstrated when

> students [of nuclear safety, for example] typically know little about the problems and values of other students in other disciplines [like nuclear security or safeguards, for example], which is a precursor to the lack of awareness in the real world.[2, p. 21]

Further, recent research in engineering education indicates that future engineers "need to be able to deal with complex interrelationships that include not only technical issues…but human and environmental factors as well"[3, p. 2]. This statement is perhaps could not be more relevant for human resource development in countries pursuing new nuclear energy programs.

In response, a focus arose to implement a multidisciplinary education program—seeking to synchronize both technical and non-technical aspects of nuclear energy safety, security and safeguards—that balanced the advantages of more deeply theoretical academic programs with the applied, practical knowledge of hands-on training courses. Further, by incorporating this range of topics across nuclear energy disciplines into the educational program, potential graduates were expected to have an increased "awareness of the social impact of their chosen [nuclear energy program-related] profession"[4, p. 133]. The result was the Gulf Nuclear Energy Infrastructure Institute (GNEII), housed at Khalifa University of Science and Technology (KU) located in the United Arab Emirates (UAE). From its inception, GNEII's goal was to help generate expertise among future leaders of Gulf-region nuclear power programs in global standards, norms and best practices in safety, security and safeguards.[5] GNEII does not provide a short course training program (e.g., like the various topic-specific courses offered by the International Atomic Energy Agency [IAEA]), nor does it provide a university-based nuclear engineering degree. Rather, it is a multidisciplinary human capacity development institute offering education, research and technical services to support responsible nuclear energy programs.[6]

GNEII's creation emerged from a strategic partnership between Emirati implementers (KU) and stakeholders (the Emirates Nuclear Energy Corporation [ENEC], Nawah Energy Company, the Federal Authority for Nuclear Regulation [FANR], the Critical Infrastructure and Coastal Protection Authority[CICPA]), and the National Emergency Crisis and Disaster Management Authority [NCEMA]), as well as US implementers (Sandia National Laboratories [SNL] and Texas A&M University's Center for Nuclear Security, Science, and Policy Initiatives [NSSPI]) and sponsors (U.S. National Nuclear Security Administration's offices of Global Material Security and Nonproliferation and Arms Control and the U.S. Department of State's Partnership for Nuclear Security). For more details, please Williams, et. al (2019) [7]. Over its developmental history, nearly 100 regional nuclear professionals have completed this novel, multidisciplinary education program (Table 1).

Table 1. Summary of GNEII Fundamentals Course Fellows 2011-2016

Year	# UAE Fellows			# Non-UAE Fellows	Yearly Total	Countries Represented
	ENEC*	**FANR**	**CICPA**			
2011	4	5	1	0	10	UAE
2012	3	9	2	8	18 (22)**	UAE, Kuwait, Saudi Arabia, Qatar, Jordan
2013	4	6	3	7	20	UAE, Saudi Arabia, Qatar
2014	6	3	3	0	12	UAE
2015	7	4	5	2	18	UAE, Jordan
2016	2	16	3	0	21	UAE
TOTAL	**26**	**43**	**17**	**17**	**99**	**5**

*Includes Fellows from Nawah, the NPP operating company that split from ENEC in 2016.
**Due to modular structure of the course in 2012 not all international participants were able to finish all required modules due to logistical reasons.

GNEII's Educational Approach

In support of the GNEII's human resource development objectives, the institute's Fundamentals Course was based on a multidisciplinary, systems theory-based pedagogical approach consisting of two key elements. First was the multidisciplinary approach, similar to Gorman, et. al (1995) [8] and Rhee, et. al (2014) [2], to help new nuclear professionals identify where nuclear energy safety, security and safeguards (3S) interdependencies to exist. This also helped emphasize the need for future nuclear energy program leaders to manage across these aspects, as responsible nuclear energy decisions often require interactions between safety, security and safeguards. Second was a systems-thinking based program structure similar to that described by Bozkurt and Helm (2013)[9] underlying their *Systems Engineering Framework* for online education development. Here, the systems engineering concepts of a *holistic view*, *life-cycle orientation*, *identification of system requirements*, and *interdisciplinary effort* helped develop our responsible nuclear energy program (RNEP) framework, which reframed the multidisciplinary aspects of nuclear energy enterprises in systems theory terms.[10] [11] The Fundamentals Course, the faculty coordinator oversaw a rotation of U.S., UAE and global subject matter experts as lecturers in support of this multidisciplinary curriculum. Lastly, the course combined lectures, hands-on activities, classroom exercises and case studies to help meet course learning objectives. More

details of this multidisciplinary curriculum can be found in Williams, et. al (2015b) [12] and Williams, et. al (2012) [10].

To further support this novel educational approach, GNEII identified and established three areas of institutional research emphasis: integrated 3S methodologies, nuclear infrastructure development and Gulf/Middle East regional nuclear interactions. Research-related activities Include expanding the analytical depth of Fundamentals Course and Visiting Research Scholar projects. More details on the research pillar can be found in Williams, et. al (2015a) [13]. Additional efforts were undertaken to enhance the institute's capabilities (and opportunities) to provide 'hands-on,' practical experiences—to include exercises in KU's nuclear engineering department laboratories, tours of the Barakah Nuclear Power Plant (2012) and (the state-of-the-art) radiation portal monitoring system at Khalifa Port in Abu Dhabi (2014-2016). These activities developed into both a way to provide regional stakeholders with short-term, technical and targeted nuclear energy-program services and create a new set of capabilities for the institute. For more details on the technical services pillar, please see reference [14].

Research Questions

To support the compelling accomplishments of the institute, this study aims to better identify and characterize GNEII's overall impact in two parts. First, this study evaluates the efficacy of implementing an integrated 3S curriculum in a Gulf region and new nuclear context for knowledge transfer. More specifically, it analyzes the development of GNEII's multidisciplinary 3S paradigm and curriculum via the effectiveness of GNEII's Fundamentals Course. Second, it analyzes GNEII's impact on a broader scale (e.g., beyond knowledge transfer) by assessing GNEII's influence on Emirati, regional and international discourse on responsible nuclear energy program development. In summary, the two research questions are:

- *RQ1:* Can a multidisciplinary approach to '3S' curriculum be implemented in a regional educational program?
- *RQ2:* What is the institutional impact of GNEII?

Design/Method

To answer these two research questions, we use a mixed methods approach and several data sources. Mixed method research designs are useful for addressing multiple facets of complex issues and reconciling trends and insights from different perspectives.[15] In addition, "using multiple methods to gather and analyze data is necessary to paint a more comprehensive picture of complex phenomena like student learning and development"[16, p. 323], making this research approach appropriate for the aims of this study. As such, we included quasi-experimental survey and context analysis for "triangulating multiple sources of data to establish trustworthiness and consistency in interpretation"[17, p. 9]. Our data sets are summarized in Table 2. This mixed methods approach is appropriate for evaluating our wide-ranging research questions by providing a framework by which to triangulate findings across traditional and non-traditional data sources.

Table 2. Summary data set descriptions

Data Set Name	Date Set Description
Course Evaluation Data	Fellow reviews of the weekly course topics from the 2011 and 2016 GNEII Fundamentals Courses
GNEII Alumni Survey Data	Online survey responses from alumni of the GNEII Fundamentals Course that consisted of 15 questions of various types
Capstone Project Data	The total set of Capstone Projects completed by the 99 GNEII Fellows across the six years of the Fundamentals Course
GNEII-Related Literature Data	Professional reports and academic articles (not authored by institute-affiliated personnel) that mention/describe GNEII

Data Set #1: GNEII Fundamentals Course Feedback

Each iteration of the GNEII Fundamentals Course between 2011 and 2016 asked the participants to complete evaluation forms to collect feedback on the success of the various course topics. The goal of this evaluation mechanism was to identify how to improve the Fundamentals Course itself. The specific questions asked were adjusted from year to year and to better align with strategic institute decisions (e.g., the 2016 evaluation form being influenced by the UAE national education accreditation process). Yet, there are close enough qualitative similarities in certain items—for example, *The instructor demonstrated a thorough knowledge of the subject matter* in 2011 and *The instructor presented material clearly and lectures were well organized* in 2016—to elicit insights regarding the success of each topic to meet GNEII's educational and knowledge transfer goals. The feedback for the evaluation was provided on a 1-to-5 Likert scale, where a '1' is the lowest possible and a '5' is the highest possible score.

This data set is composed of Fundamentals course topical feedback forms from 2011 and 2016. The 2011 data set consisted of 12 weekly topics and eight (8) evaluation questions while the 2016 data set consisted of 10 weekly topics and 13 questions. The 2011 weekly topics were collapsed to match those in the 2016 data by averaging the associated feedback scores between the combined weekly topics. Then, as summarized in Table 3, the actual feedback questions were collapsed (and the respective scores averaged) into three common categorical measures: instructor effectiveness, course structure effectiveness and overall topic effectiveness.

The analytical goal of this data set was to measure the improvement between the first (2011) and last (2016) offerings of the GNEII Fundamentals Course to meet the professional development needs of the Fellows (and address RQ1). The unit of analysis is the individual response from each Fellow for each question evaluating a course topic. Given demographic similarity between the two groups of Fellows (see Table 1), comparison between the evaluation scores registered in 2011 versus those in 2016 is appropriate for eliciting insights from this data set. More specifically, the degree to which the responses are the same or improve from 2011 to 2016 supports an affirmative response to RQ1, indicating that (near) real-time feedback from Fellows represents (at worst) consistency with and (at best) improvement in instructor, course structure and overall topic effectiveness.

Table 3. Summary of the evaluation categories for the GNEII Fundamentals Course 2011 & 2016 weekly topic feedback forms.

Evaluation Category	Specific Course Evaluation Question: 2011	Specific Course Evaluation Question: 2016
Instructor Effectiveness	• The instructor was well prepared for the presentation? • The instructor demonstrated a thorough knowledge of the subject matter. • The instructor interacted well with the participants? • The instructor clearly expressed interest in addressing all questions raised by the participants? • The instructor's response to questions was clear and understandable?	• The instructor's activities/exercises and slides helped me achieve the learning outcomes • The instructor kept good discipline in the classroom • The instructor showed enthusiasm for the subject matter • The instructor was available for help outside of class • Assessment and feedback was fair and prompt by the instructor • The instructor included sufficient relevant examples
Course Structure Effectiveness	• The materials (handouts, on-screen visuals, videos, job aids, etc.) provided and reviewed were easy to understand? • The materials (handouts, on-screen visuals, videos, job aids, etc.) provided and reviewed offered valuable information that will help me in the future.	• The instructor presented material clearly and lectures were well organized • The instructor's activities/exercises & slides helped me achieve the learning outcomes • The instructor kept good discipline in the classroom • The instructor showed enthusiasm for the subject matter • The instructor was available for help outside of class • Assessment and feedback was fair and prompt by the instructor • The instructor included sufficient relevant examples • Overall, I am fully satisfied with the module content
Overall Topic Effectiveness	• The materials (handouts, on-screen visuals, videos, job aids, etc.) provided and reviewed offered valuable information that will help me in the future. • The length of the presentations was sufficient to deliver the subject matter?	• The module was informative and helped me develop an interest in the subject • I believe I achieved the learning outcomes of the module • The content of this module is relevant to my needs/interests/job responsibilities • The instructor presented material clearly and lectures were well organized • The instructor's activities/exercises and slides helped me achieve the learning outcomes • The instructor kept good discipline in the classroom • The instructor showed enthusiasm for the subject matter • The instructor was available for help outside of class • Assessment and feedback was fair and prompt by the instructor • The instructor included sufficient relevant examples • Overall, I am fully satisfied with the module content • Overall, I am fully satisfied with the module delivery • Overall, I am fully satisfied with this module

Data Set #2: GNEII Alumni Survey Data

From October 23 to November 13, 2016, GNEII alumni were given the opportunity to complete an anonymous online survey regarding their experiences during, and after completing, the GNEII Fundamentals Course. The survey was administered via Survey Monkey™ and was preceded by an introductory email sent to the alumni via the last known email address they had provided to the institute. The survey consisted of multiple question types (e.g., Likert Scales, multiple choice and open-ended) that were organized around two key themes. [NOTE: Please contact the authors for the actual survey text.] The first theme sought to elicit how much each Fellow learned from completing the GNEII Fundamentals Course. The second theme sought to elicit how much completing the GNEII Fundamentals Course improved their capability to perform their current job tasks. In total, 29 of 99 alumni responded for a 31% response rate (summarized in Table 4).

Table 4. Summary of GNEII Alumni Respondents to 2016 Online Survey.

Year	# UAE Fellows			Affiliation Not Reported	Total
	ENEC	FANR	CICPA		
2011	--	--	1	--	1
2012	1	2	--	1	4
2013	1	1	--	2	4
2014	1	1	--	--	2
2015	6	--	1	1	8
2016	1	7	--	2	10
TOTAL	**10**	**11**	**2**	**6**	**29**

The analytical goal of this data set was to assess the knowledge improvement within GNEII Fundamentals Course alumni in key topical areas (and address RQ1) and to evaluate the impacts of the course on the Fellows' professional careers (and address RQ2). Here, the unit of analysis is similarly the individual response from each Fellow for each survey question. More specifically, this manifests itself in numerical comparisons of reported Likert Scale scores (e.g., between Q4 and Q5), numerical counts (e.g., for Q6) and assessing trends across years (e.g., Q9). In addition, the affirmative evidence for RQ1 was dependent upon the extent to which:

- the level of knowledge in various topics before versus after the Fundamental Course decreases, sustains or increases (Q 4 and Q5);
- the most often selected topic is related to either the 3S, security, safety or safeguards topics as most useful (Q6);
- Fellows select either moderate or substantial impact on knowledge regarding 3S, security, safety or safeguards topics (Q7); and,
- trends increasingly agree or strongly agree on the benefit of the novel 3S approach (Q8).

Similarly, the larger institutional impact (RQ2) of GNEII was measured by the extent to which:

- Fundamentals Course topics were considered relevant to current job duties (Q9);
- the knowledge and experiences from the Fundamentals Course help in advancing professional careers (Q10);
- the knowledge and experiences from the Fundamentals Course are regularly used in the professional environment (Q11); and,
- the knowledge and experiences from the Fundamentals Course help in building overall professional opportunities (Q12).

Data Set #3: GNEII Fundamentals Course Capstone Project Data
For each iteration of the GNEII Fundamentals Course, Fellows were required to complete a Capstone project. (NOTE: All GNEII Capstone projects are catalogued as 'GNEII Working Papers,' and can be accessed by contacting co-authors Dr. Philip A. Beeley or Dr. Saeed Al-Ameri at KU.) Per the Fundamentals Course requirements, the Capstone was a short-term, applied research project that allowed Fellows the opportunity to focus their newly gained knowledge to address a real nuclear infrastructure development problem, need or issue [13]. These Capstone Projects served as metrics by which to evaluate Fellow performance at the end of the Fundamentals Course, opportunities for the Fellows to demonstrate their analytical capability to professional peers and tangible evidence of potential solutions to current problems with which they could return to their employer. Though a set of secondary data, the centrality of the Capstone Project to the Fundamentals Course make this data appropriate for exploring our research questions.

The analytical goal of this data set was to (1) assess the increase in topical and technical sophistication in Capstone Projects (to address RQ1) and (2) the possibility of extending Capstone Projects research ideas into more in-depth academic research projects within the institute (to address RQ2). The unit of analysis in this data set is the individual Capstone Project report and each was evaluated for sophistication in terms of research design, technical depth, topical complexity and logical consistency. According to this content analysis, the larger the increase in sophistication of the Capstone Project reports the greater the knowledge transfer during the Fundamentals Course (addresses RQ1). It is important to note that the increased sophistication of Capstone Projects is not a measure of *absolute* knowledge transfer, particularly when considering the possibility for a steady increase in the overall baseline knowledge of subsequent classes of GNEII Fellows. That said, this data set can speak to how knowledge transferred expanded beyond the *relative* baseline level(s) of each class of Fellows completing the Fundamentals Course. Similarly, the extent to which these Capstone Projects produced follow-on research efforts is one measure of the broader (e.g., beyond knowledge transfer) impact of GNEII (addresses RQ2).

Data Set #4: GNEII-Related Literature Data
Over the course of GNEII's operations, the institute has built a strong, positive reputation and was increasingly referenced in professional fora (e.g., conferences and professional society meetings) and invited to participate in regional and technical exchanges in relevant topic areas. As such, this data set, summarized in Table 5, consists of all references to GNEII within the academic and professional publication space. By using a range of online search capabilities (e.g., Google Scholar and SCOPUS™), the terms "GNEII" and "Gulf Nuclear Energy Infrastructure Institute" were queried to identify these data, with the final search occurring on October 16, 2019. (NOTE: We excluded all search returns that were authored or co-authored by institute-related professionals.)

The analytical goal of this data set was to assess the topical and geographic range over which GNEII is described in the professional and academic literatures. The unit of analysis is the individual document and each was evaluated for how and why the institute was described. As such, the larger the topical and geographic spread of references to GNEII within the professional

and academic literatures—and the deeper the description or analysis of GNEII—the larger the institutional impact (to address RQ2).

Table 5. Summary results of GNEII-related searches in academic databases.

Year		Article/Chapter Title	Source
2011	A	The status of renewable energy in the GCC countries	Renewable and Sustainable Energy Reviews
	B	Models for Aspirant Civil Nuclear Energy Nations in the Middle East	Energy Security Initiative at Brookings Institute
	C	Inside a U.S. Embassy: Diplomacy at Work, The Essential Guide to the Foreign Service	(Potomac Books)
2012	D	Nuclear Energy in the Gulf Cooperation Council States	Security Index: A Russian Journal on International Security
	E	Going Nuclear in the GCC Countries: Rationale, Challenges, and Politics (Chapter)	The GCC Economies: Stepping up to Nuclear Challenges
	F	Energy Security: The United Arab Emirates	Asian Affairs
	G	Human Resource Development in New Nuclear Energy States: Case Studies from the Middle East	Energy Security Initiative at Brookings Institute
	H	An Assessment of the Nuclear Security Centers of Excellence	The Stanley Foundation
2013	I	The challenge of shale to the post-oil dreams of the Arab Gulf	Energy Policy
	J	The United Arab Emirates (Chapter)	The Palgrave MacMillan Alternative Energy in the Middle East
	K	Containment Through Cooperation: A Proposal for a Nuclear Energy Agreement with Iran	James A. Baker III Institute for Public Policy
	L	Nuclear Weapons: The State of Play	Centre for Nuclear Non-Proliferation and Disarmament
2014	M	The Strategic Context of the UAE's Nuclear Project: A Model for the Region?	Middle East Policy
2015	N	Civilian Nuclear Development in the Arabian Peninsula: Prestige, Energy, and Iran	Journal of Arabian Studies
	O	The Arab Gulf States and the Knowledge Economy: Challenges and Opportunities	The Arab Gulf States Institute in Washington
2016	P	U.S. National Laboratory Contributions to Global Nuclear Security	Brookhaven National Laboratory
	Q	Nuclear Regulation in New Jurisdictions: The United Arab Emirates in Comparative Perspective	Presented at the Annual Meeting of the International Political Science Association
2017	R	A New Era for Energy: The Nightmare Gulf Scenario and Implications for Human and Environmental Security (Chapter)	Environmental Change and Human Security in Africa and the Middle East
	S	Promoting nuclear security in the Middle East	Bulletin of the Atomic Scientists

	T	On the Impact of Scientists and Engineers on Global Nuclear Security	Presented at a Federation of American Scientists event
2018	**U**	Confidence Today, Weapons of Mass Destruction Free Zone in the Middle East Tomorrow (Chapter)	Energy Transitions in the Gulf: Key Questions on Nuclear Power
2019	**V**	Mapping the Emergence of International University Research Ventures	Journal of Technology Transfer

In summary, combining the quasi-experimental *Course Evaluation Data* and *GNEII Alumni Survey Data* with the secondary *GNEII Capstone Project Data* and *GNEII-Related Literature Data* provided rich, substantial data with which to evaluate trends, findings and insights that address our research questions.

Results

Analysis of Data Set #1: GNEII Fundamentals Course Feedback

Overall, the responses across the three evaluation categories—instructor, course material and overall topic effectiveness—for all weekly topics in both 2011 and 2016 range from 3.8 to 4.8 and illustrate a high level of consistency in response from the Fellows. In terms of instructor effectiveness (Figure 1, [A]), the data show a decrease in five topic areas (e.g., *Critical, System & 3S Thinking*), an increase in four topic areas (e.g., *Security II*) and no change in the *Nuclear Fuel Cycle History & Policy* topic area. In terms of course material effectiveness (Figure 1, [B]), the data show a decrease in only three topic areas (e.g., *Nuclear Power Operations & Systems*) and an increase in seven topic areas (e.g., *Safeguards II*). Lastly, in terms of overall topic effectiveness (Figure 1, [C]), the data show a decrease in the same three topic areas as the course material effectiveness, an increase in six topic areas (including the same seven topic areas as course material effectiveness except for *Security I*) and no significant change in the *Security I* topic area.

The data suggests that the Fundamentals Course instructors were able to adjust successfully to Fellow concerns despite the reported decline in five topic areas. Further, any negative influence of decreasing instructor effectiveness seemed offset by the increase in both course material and overall topic effectiveness. These trends illustrate that the multidisciplinary design of the Fundamentals Course successfully transferred knowledge across this broad set of topics and improved over time. An additional trend of note was the decrease in all three effectiveness categories for the *Critical, Systems & 3S Thinking*, *Nuclear Power Operations & Systems*, and *Safety I* weekly topics (averaging 0.35), which was inconsistent with the other trends. Though not explicitly investigated in this study, possible causes for this categorical decline in effectiveness of these topics include the increased expertise (perhaps as a result of GNEII alumni matriculating through regional nuclear energy programs) of the Fundamentals Course Fellows between 2011 and 2016.

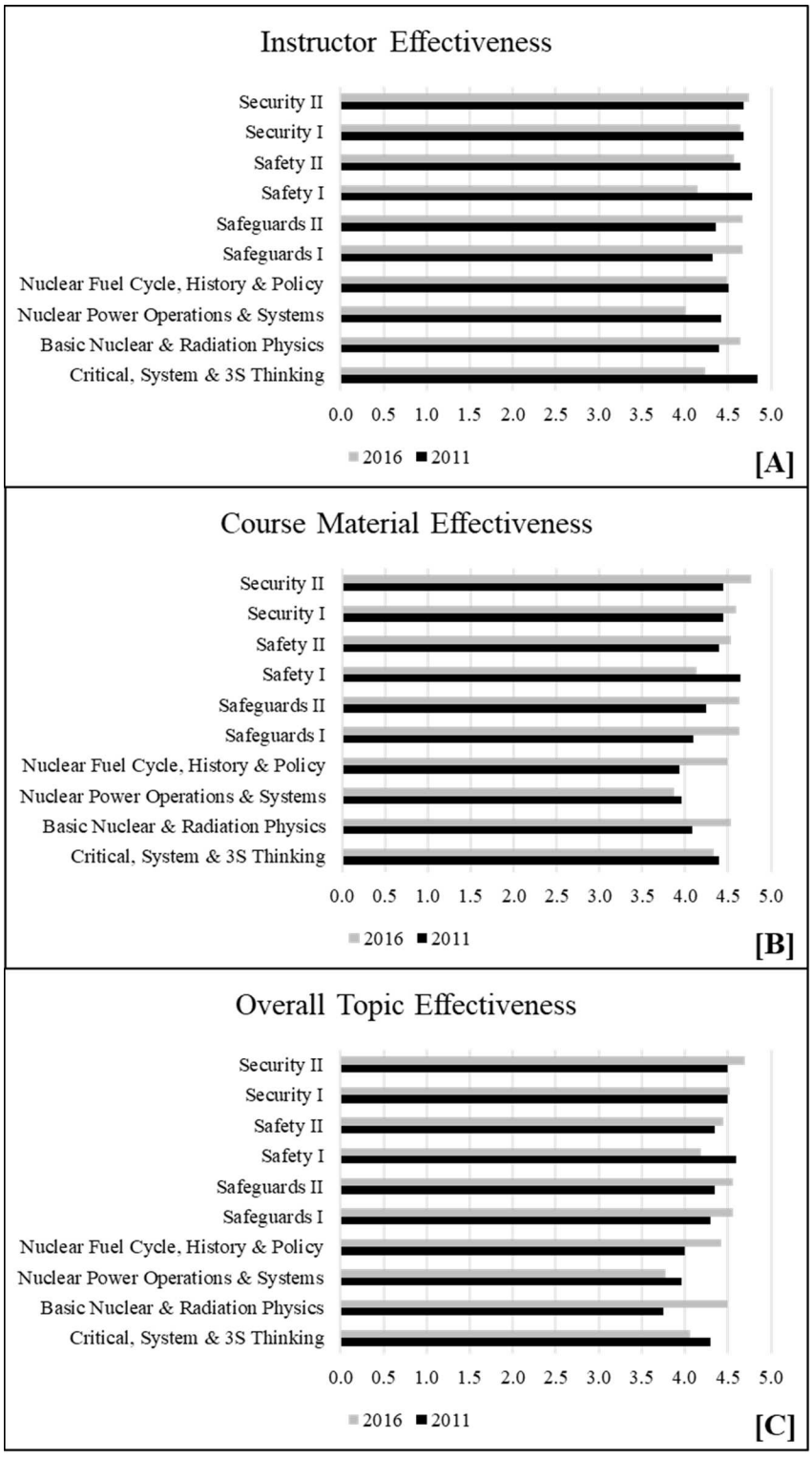

Figure 1. Analytical results from the evaluation categories for the GNEII Fundamentals Course 2011 & 2016 weekly topic feedback forms for [A] Instructor Effectiveness; [B] Course Material Effectiveness; and, [C] Overall Topic Effectiveness.

On average, the *GNEII Fundamentals Course Feedback* data showed improvements across most of the other weekly topics for each of the three evaluation categories between 2011 and 2016. There is also an indication that course material and overall topic effectiveness can compensate for weaker instructor effectiveness—another insight suggesting success in implementing this multidisciplinary 3S curriculum to convey the wide range of complex issues facing new countries pursuing responsible nuclear energy programs. As such, these results directly address RQ1 and the improvement across all effectiveness measures from 2011 to 2016 suggests that a 3S-based curriculum can be implemented in a regional education program.

Analysis of Data Set #2: GNEII Alumni Survey Data

Comparing the responses to Q4 (level of knowledge BEFORE the course) and Q5 (level of knowledge AFTER the course) described the increase in the level of knowledge across all topics for all years of response. (NOTE: The response from the lone 2011 respondent was omitted because they indicated an increase from 1 to 5 on all topics, which skewed the data representation.) Figure 2 indicates the normalized change in knowledge levels for each year of the Fundamentals Course and shows that 2012, 2015, and 2016 Fellows each had at least a 50% increase across all topics. Respondents also indicated that, overall, the *Critical, System & 3S Thinking* and the *Basic Nuclear & Radiation Physics* topics both decreased in reported knowledge transfer from 2011 to 2016—which may be partially explained by an overall increase in knowledge of or increased comfort with these topic areas. Likewise, the *Nuclear Power Operations & Systems, Nuclear Safeguards, Nuclear Safety* and *Nuclear Security* topics all averaged an increase in reported scores between 2011 and 2016—which may be partially due to a better alignment of these topics with the GNEII stakeholder (and Fellow) needs. Lastly, the *Nuclear Fuel Cycle, History & Policy* showed the most consistent rating and the *Nuclear Safeguards* recorded the highest average.

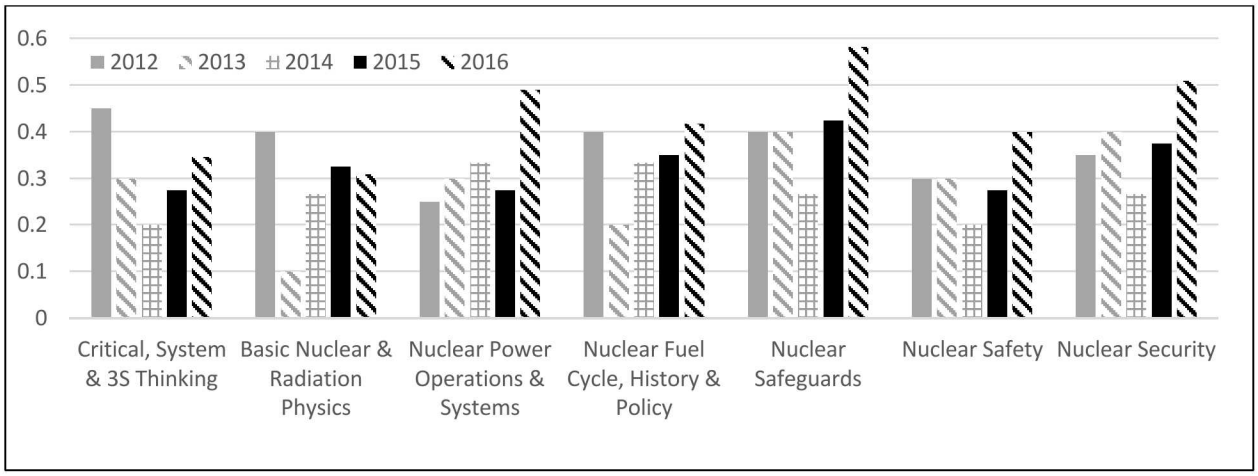

Figure 2. Normalized Percentage Improvement in Level of Knowledge for GNEII Fundamentals Course Topics (from Q4 and Q5 in the GNEII Fellow survey).

The survey results also indicated that the Fundamentals Course at least moderately increased their understanding of nuclear security (Figure 3[A]), safety (Figure 3[B]), safeguards (Figure 3[C]) and nuclear energy 3S (Figure 3[D])—with a lone respondent indicating a minimal

increase over their current knowledge of nuclear safety. These results are consistent with Figure 2, wherein the Fellows reported higher levels of positive impacts on their understanding of safeguards, safety and security from the Fundamentals Course. The consistency in these responses (55% to 72% of moderately increased knowledge of safeguards, safety and security independently—and for the 3S collectively) indicate the success of this multidisciplinary pedagogy based on an integrated 3S approach.

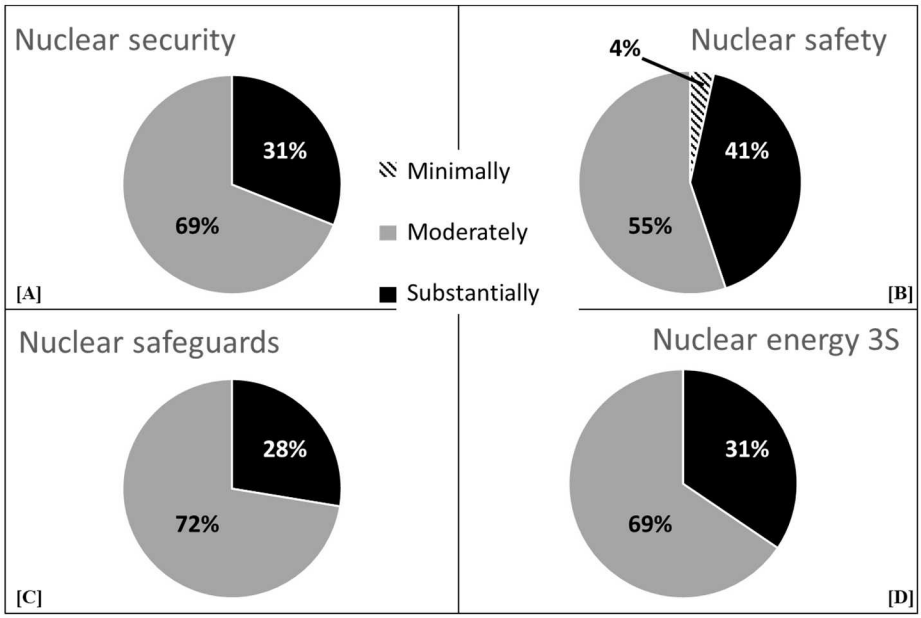

Figure 3. Description of how the GNEII Fundamentals Course impacted the statement 'In the GNEII Fundamentals Course, I {minimally, moderately, substantially} increased my knowledge of nuclear security [A], safety [B], safeguards [C] and nuclear energy 3S' [D] (from Q7 in the GNEII Fellow survey).

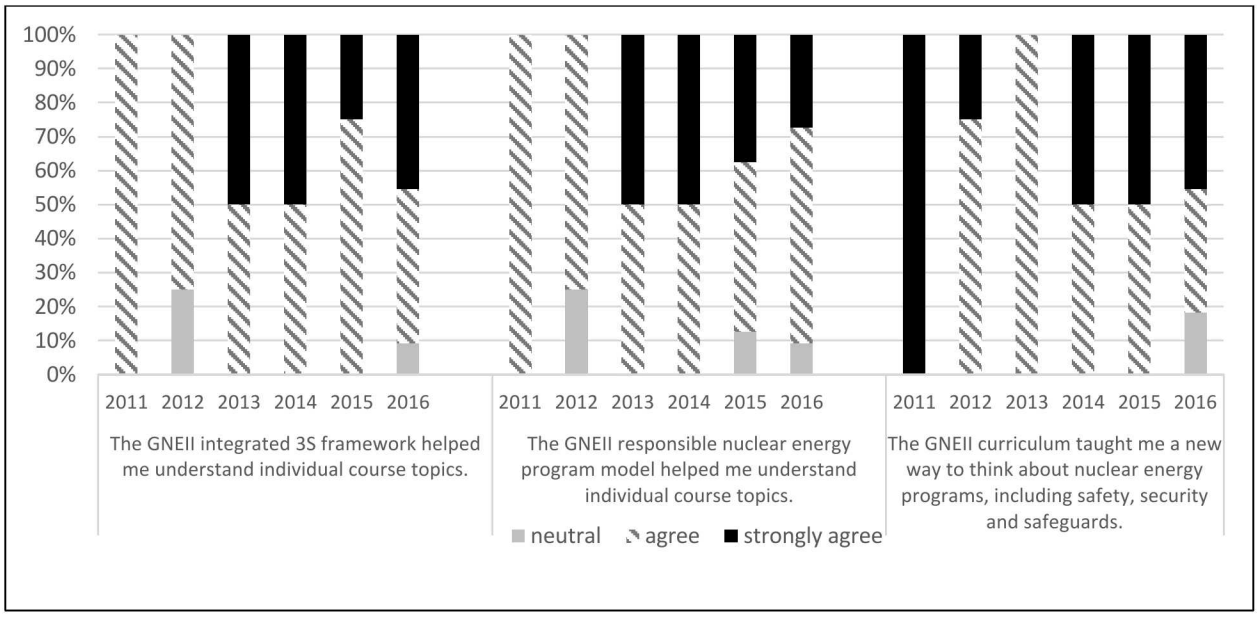

Figure **4** illustrates how respondents evaluated how much they (dis)agreed with statements about the effectiveness of the 3S approach (and in particular the responsible nuclear energy program model) in helping them better understand course topics and whether or not the GNEII curriculum taught them a new way to think about this range of nuclear energy-related issues. The near identical (neutral, agree and strongly agree) responses regarding the utility of the *integrated 3S framework* and the *responsible nuclear energy program model* (left and center charts, respectively) illustrate close alignment of the two main teaching aids for the Fundamentals Course. Lastly, the primary elements of this multidisciplinary, integrated 3S approach to nuclear energy infrastructure education all seemed to have increased the knowledge transfer for individual topics.

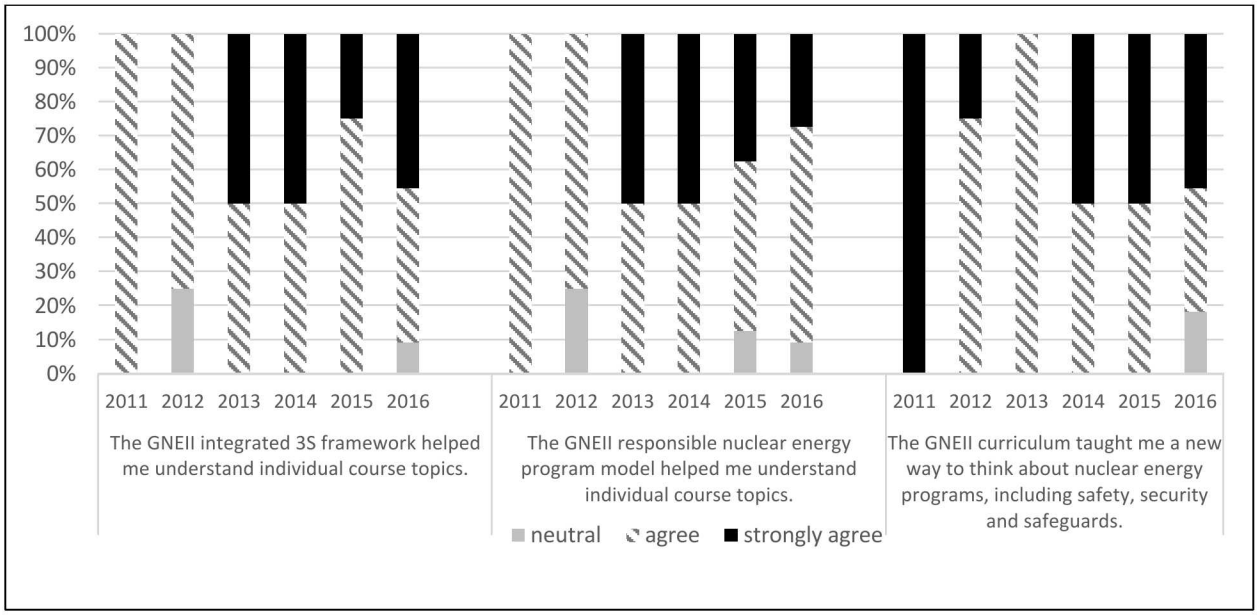

Figure 4. Description of the relevance of the GNEII 3S framework [A] & responsible nuclear energy program model [B] for understanding—and extent to which they provided a new way of thinking about [C]—individual Fundamentals Course Topics (from Q8 in the GNEII Fellow survey).

Figures 2-4 represent how Fellows described their knowledge transfer for key nuclear energy infrastructure development topics from GNEII's multidisciplinary, integrated 3S curriculum and pedagogical approach and support RQ1.

The remaining survey questions evaluated the impact of the knowledge gained during the GNEII Fundamentals Course outside the classroom.

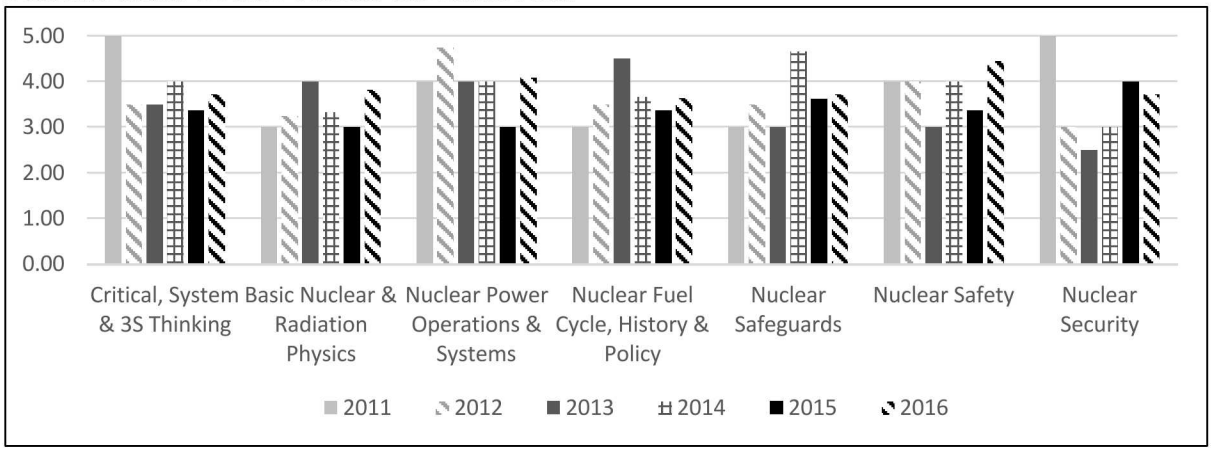

Figure **5** illustrates the reported relevance of each course topic to the Fellows' current job responsibilities. The average of each Fundamentals Course class, except for 2013, averaged at least a 3.0 for the importance of all topics. The two topics that averaged the highest reported impact were *Critical, System & 3S Thinking* and *Nuclear Power Operations & Systems*. Likewise, both the *Nuclear Fuel Cycle, History & Policy* and *Nuclear Safeguards* topics trended toward an increasing impact on job responsibilities between 2011 and 2016, while *Nuclear Security* trended toward a decreasing impact (possibly due to the separate entity for security in the UAE and the lack of interaction opportunities).

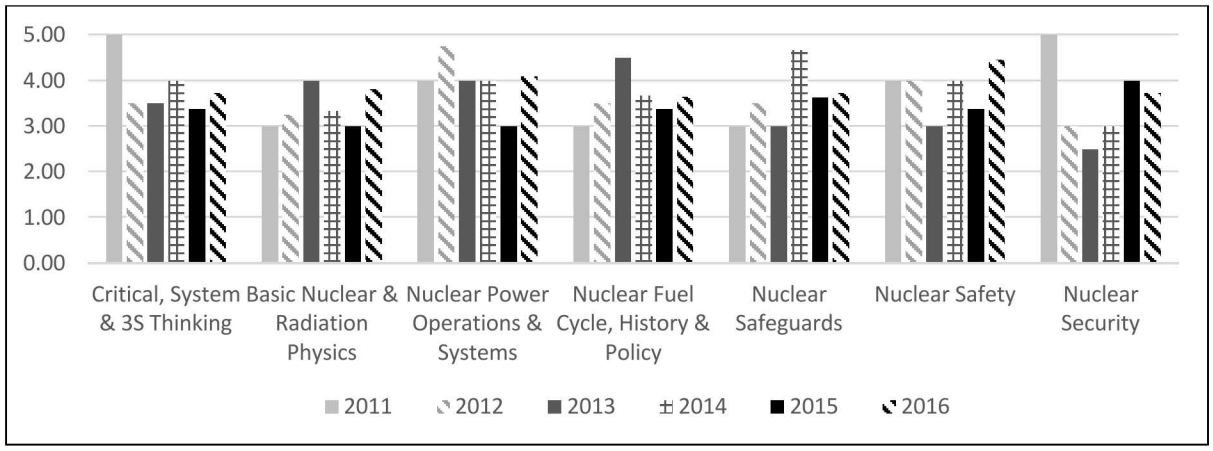

Figure 5. Description of the relevance of the GNEII Fundamentals Course topics to current job duties of respondents (from Q9 in the GNEII Fellow survey).

The respondents also commented on their beliefs of how the course aligned with their current professional responsibilities (Table 6) with all but one stating that the GNEII Fundamentals Course *has helped me advance in my career*—and a majority of those strongly agreeing. Similarly, and speaking to the relevance of the course topics, respondents described how the Fundamentals Course also prepared them for real nuclear energy infrastructure job

responsibilities. Here, 83% at least agreed with the relevance of the Fundamentals Course to job responsibilities and 86% believed that Fundamentals course made them better prepared.

Table 6. Description of how the knowledge & experiences from the GNEII Fundamentals Course influence current & future job possibilities (from Q10 & Q12 in the GNEII Fellow survey).

Survey Question \ Degree of Agreement		Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Q10a	HAS helped me advance in my professional career in nuclear energy	0%	3%	0%	41%	55%
Q10b	WILL help me advanced in my professional career in nuclear energy	0%	3%	3%	41%	48%
Q12a	Was relevant to my job duties	0%	0%	17%	34%	48%
Q12b	Made me better prepared to succeed at my job	0%	0%	14%	41%	45%

Lastly, respondents commented on the actual utility of the GNEII Fundamentals Course in terms of daily professional responsibilities. As summarized in Figure 6, approximately 60% of Fellows used the knowledge gained from the Fundamentals Course at least weekly (and 80% used it at least monthly). In terms of communicating across professional disciplines (and organizational stovepipes), only 50% of Fellows indicated they do so on at least a monthly basis.

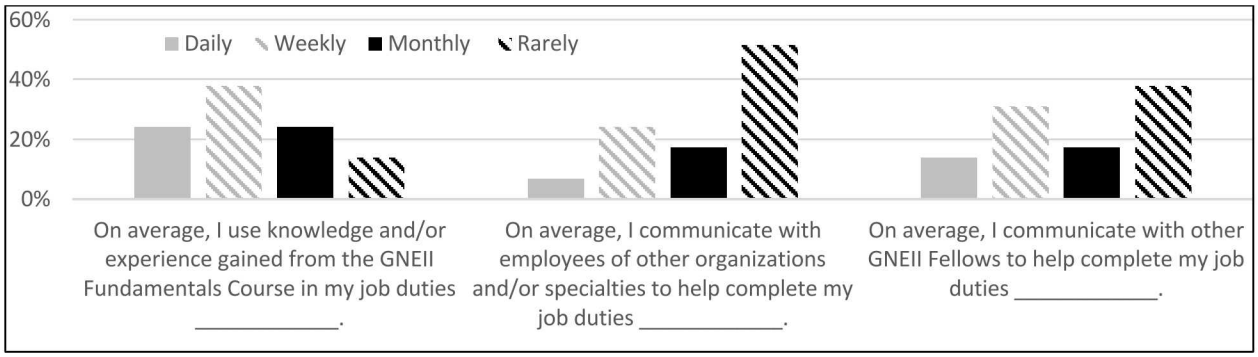

Figure 6. Description of the frequency with which GNEII Fundamentals Course experiences impacts regular professional duties/tasks (from Q11 in the GNEII Fellow survey).

Figures 5 and 6 and Table 6 illustrate the reported impact of the GNEII Fundamentals Course in the nuclear energy infrastructure professional workplace and supports RQ2 of describing GNEII's broader institutional impact.

Analysis of Data Set #3: GNEII Fundamentals Course Capstone Project Data

Reviewing the 45 Fundamentals Course Capstone Projects produced between 2011 and 2016 provided additional evidence for exploring the impact of GNEII. As shown in Table **7**, there was a good spread of the Capstone Projects across GNEII's three core competency research areas.[13] Some of the Capstone projects address more than one core competency research area and were subsequently categorized in more than one area. Consider, for example,

how the 2014 Capstone Project 'Evaluation of Security and Safeguards Measures for the Transportation Security in the UAE' addresses both 3S methodologies and infrastructure development. (NOTE: This explains why there are 52 entries in Table **7** and only 45 Capstone Projects.)

Table 7. Categorization of GNEII Capstone Projects by Core Research Competencies

Core Competency Research Area	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Integrated 3S methodologies	1	1	4	4	2	3
Nuclear infrastructure development	0	6	4	4	4	3
Gulf/Middle East regional nuclear interactions	1	4	3	1	4	3

Three criteria were developed to address the breadth, depth, sustainability and appropriateness of the Capstone Projects. The first criterion was the *technical sophistication* of the research, where weak projects did little more than match experiences or literature-based information to Fundamentals Course concepts and strong projects illustrated a deep technical understanding of the topic by identifying gaps and suggesting solutions. The second criterion was the *methodological complexity* of the research. Here, depth of understanding ranged from basic literature reviews to conducting experiments. Lastly, the third criterion was the *analytical depth* of the research. The Capstone Projects were reviewed for the types of conclusions provided, specifically searching for simple, intuitive insights or data-supported non-intuitive (and interesting!) insights. Table 8, below, shows a representative set of the Capstone Projects based on this evaluation rubric.

Table 8. Representative set of GNEII Capstone Projects categorized according to three (3) evaluation criteria (with increasing research quality from left to right).

Technical Sophistication		
Basic Concept Mapping	**Technical Summaries**	**Solutions for Identified Technical Limitations**
Integrations of Safety, Security & Safeguards (2011)[a]	*Safety, Security, and Safeguards Challenges for Building a Final Repository for Spent Fuel in the UAE* (2013)[a]	*Operational Security and Information Protection in the Areas of 3S* (2015)[a]
Effects of the Environment on Nuclear Power Plant Operations (2011)[b]	*An Initial Radiation Baseline Study of Urban Environment in Abu Dhabi* (2014)[b]	*Evaluation of Cosmic-Ray Dose in the UAE* (2016)[b]
Methodological Complexity		
Basic Literature Review & Summary	**Advanced Literature Review & Identifying Gaps**	**Real Data Collection [Experiment]**
A Qualitative Assessment of Fuel Fabrication Options in the UAE (2013)	*Survey of the Current Spent Nuclear Fuel Storage Technologies & Assessing Safety Approaches of Existing Systems*	*Measurements of radionuclides concentration in UAE cucumber* (2016) [Experiment]

	for Barakah Nuclear Power Plant (BNPP) (2014)	
SBO Roles and Mitigation Plan (2012)	*Evaluation of Threats by Drones to a Nuclear Power Plant*** (2015)	*Neutron activation of living insects for safety and security applications* (2016) [Experiment]
Analytical Depth		
Intuitive Insights	**Non-Intuitive Insights**	**Non-Intuitive Insights Supported by Data**
Filling the Gaps Between Safety and Security (2013)	*Development of Recommendations for the Nuclear Security Culture in the* UAE (2014)[c]	*Mitigation of national cultural differences effects during safety, security emergency at an NPP site* (2016)[c]
Transparency in Nuclear Security (2012)	*Safety, Security, and Safeguards Challenges for Building a Final Repository for Spent Fuel in the UAE*** (2013)	*Investigation on the Sensitivity of UAE Domestic Agricultural Production to Radiological Contamination Following a Hypothetical Severe Nuclear Accident at Barakah NPP***** (2015)
[a]3S implementation as a common research thread over the course of GNEII 2011-2016 activities [b]Environmental effects as a common research thread over the course of GNEII 2011-2016 activities [c]Nuclear security culture as a common research thread over the course of GNEII 2011-2016 activities *Indicates a successfully presented at a professional conference **Indicates a project that served as a seed for follow-on, more in-depth research		

The data also illustrated a few research themes that were consistent throughout institute activities between 2011 and 2016—itself an indication of increasing depth in knowledge and insights being generated from GNEII. For example, the conclusions from 2014's 'Development of Recommendations for the Nuclear Security Culture in the UAE' were incorporated into the research design and data collection of 2016's 'Mitigation of national cultural differences effects during safety, security emergency at an NPP site.' This increase in analytical depth (bottom of Table 8) resulted in deeper insights on the importance of clear communication (e.g., selecting a single langue to use during emergency operations) in developing and maintaining responsible nuclear energy programs. Similar common research threads are demonstrated in the first and second row of *Technical Sophistication* in Table 8, respectively.

Lastly, several of these GNEII Capstone Projects provided the 'seed' for follow-on, more in-depth research efforts. For example, the 2015 'Evaluation of Threats by Drones to a Nuclear Power Plant' resulted in expanded analysis in both a graduate-level term paper[18] and a published article[19]. In addition, the Capstone Project 'Investigation on the Sensitivity of UAE Domestic Agricultural Production to Radiological Contamination Following a Hypothetical Severe Nuclear Accident at Barakah NPP' (2015) spurred a presentation at the 2015 'International Conference on Energy, Water and Environmental Sciences' and a published article on natural occurring radioactive material (NORM) in date palms.[20]

Ultimately, the content analysis of the 45 GNEII Capstone Projects completed from 2011 to 2016 indicated an increased technical sophistication, methodological complexity and analytical

depth of research conducted by the Fellows. It also illustrated a broader, more nuanced set of topics covered and a non-education impact of the GNEII Fundamentals Course. As a result, the ability for Fellows to complete increasingly high quality Capstone Projects, serves as evidence of successfully implementing a multidisciplinary, 3S regional education program (addressing RQ1). In addition, the expanding research portfolio, experience and reputation evidenced in the data (and the follow-on research efforts) is a measure of the broader, institutional impact of GNEII (addressing RQ2).

Analysis of Data Set #4: GNEII-Related Literature Data

Summarized in Table 9 below, the results of searches through several academic databases for references to GNEII (summarized in Table 5 and labeled with bracketed letters) yielded descriptions found in eight (8) journal articles, six (6) book chapters, six (5) published reports, two (2) conference presentations, and one (1) set of published remarks. (NOTE: Two of the authors participated in a 2011 meeting hosted by the Brookings Institute that contributed to the GNEII reference in [B]). In addition, these references to GNEII ranged from energy resource management (Renewable and Sustainable Energy Reviews [A]), regional and energy policy (Energy Policy [I] and Journal of Arabian Studies [N]) to human capacity building (the Brookings Institute [B]). Lastly, as illustrated below, slightly more than half of these publications were produced in the U.S. and the remainder were produced in other countries, including Australia and Qatar.

Table 9. Summary of Analytical Results for the GNEII-Related Literature Data Set

GNEII Reference Type	U.S.-Based	Europe-Based	Other-Based [Country]	Total
Peer-Reviewed Journal Article	M, S, V	A, D, F, I	N [Qatar]	8
Book Chapter	C, E	J, R, U	L [Australia]	6
Report	B, G, H, K, O	--	--	5
Other	P*, T	--	Q* [Canada]	3
				*Conference Presentation

These GNEII descriptions included describing GNEII as "an important step" in the UAE's development of nuclear power program [F], "the latest step in creating a nuclear nonproliferation culture in the [Gulf] region" [D], helping to "distinguish [UAE] tangibly and symbolically from its neighbors through modernization, technology, and development" [N] and "develop[ing] a responsible nuclear culture and…a regional hub for the development of human resources in direct support of their own and other regional nuclear energy programs" [U]. Similarly, 5 out of the 22 references positively described GNEII's integrated 3S educational approach, including how the institute "recognizes the importance of an integrated approach to security, safety, and safeguards in the design of these 'centres of excellence'" [L] and is a multi-institution collaboration "that has produced a successful regional institute capable of indigenizing global norms and standards in nuclear energy safety, safeguards, and security" [P]. Some additional benefits attributed to GNEII in this data include: being a good example of international cooperation between the U.S. and UAE/Gulf [G, O, P]; illustrating a positive application of scientific diplomacy [C]; serving as a strong part of UAE mission to build indigenous, highly qualified nuclear energy workforce [A, B, J, T]; increasing transparency in the UAE (and

promoting transparency in regional) nuclear power programs [K, S]; and, acting as a regional resource for developing nuclear power human capacity [D, M].

Overall, these 22 references to GNEII by non-affiliated authors suggests a larger institutional impact beyond improving knowledge transfer to the Fellows. In addition, the range of publication types in which the institute was referenced and the geographic spread of the publishers further support GNEII's growing institutional impact. The analysis of this GNEII-related literature data suggests that GNEII has a reputation for producing quality Fellows equipped with a good understanding of key nuclear energy safety, security and safeguards concepts. Further, the positive tone of these descriptions of the institute—as well as the growing topical fields using GNEII as a positive example—further indicate a growing, positive institutional impact (addressing RQ2).

Discussion

Taken together, the results of evaluating the four data sets expand upon reference[21] and provide evidence that the GNEII Fundamentals Course successfully implemented a multidisciplinary, 3S curriculum in a regional education program. The *Course Evaluation data set* illustrated improvement trends in instructor, course structure and overall topic effectiveness over GNEII activities from 2011 to 2016. Further, this data set described (near) real-time adjustments made to ensure this multidisciplinary curriculum would adequately transfer a breadth of nuclear infrastructure related knowledge. Likewise, as demonstrated in the analysis of the *GNEII Alumni Survey data set*, Fellows' responses clearly illustrate that various aspects of the Fundamentals Course pedagogy—particularly the Responsible Nuclear Energy Program model and 3S framework—yielded high levels of knowledge transfer. Lastly, the increase in quality demonstrated in the *Capstone Project data set* provides two equally plausible—and positive—outcomes. This increased quality speaks to *either* the ability of the GNEII Fellows to apply knowledge gained from Fundamentals Course to applied research topics *or* it speaks to an increased level of baseline knowledge of incoming Fellows—both of which provide new perspectives to various nuclear infrastructure development challenges.

An additional set of interesting outcomes can be gleaned from implementing the GNEII Fundamentals Course between 2011 and 2016. First, this course represented an ability to successfully provide this broad range of nuclear infrastructure development knowledge to a regional audience (e.g., Table 1). Second, because the Fellows who responded were representative of the range of occupations necessary to support responsible nuclear energy infrastructure development (e.g., utility, regulatory, security organization, other federal entities), the GNEII Fundamentals Course model is likely to help other regions/nations building up their own nuclear energy infrastructure. Third, this evidence that supports RQ1 also speaks to the flexibility and adaptability of GNEII's pedagogical model—as demonstrated in the ability to match changing stakeholder needs. For example, these results illustrate the beneficial work of the GNEII Steering Committee—whose members are described in the Introduction (more details are provided in Williams, et. al (2019) [7]—who met annually to review and update the Fundamentals Course curriculum. Lastly, these results support the design of the Fundamentals Course as a semester-long, post-graduate, professional development program to best provide Fellows a broad, sufficient overview of key topics for responsible nuclear energy infrastructure development.

Similarly, evidence across the different data sets describe the broader impact that GNEII has had *beyond* its primary goal of knowledge transfer to young and mid-career nuclear professionals from Gulf and Middle East region energy programs. More specifically, the second set of questions in the *GNEII Alumni Survey data set* provides evidence describing how the GNEII Fundamentals Course impacts the professional workplace of the Fellows in terms of increased professional capability, enhanced preparation for occupational responsibilities, providing higher performing employees, and increasing interaction across typically siloed areas of expertise. The *Capstone Project data set* illustrates GNEII's impact as an incubator for fledgling research ideas and exhibited a growing base of regional SMEs.

As a more far-reaching example, the 2016 capstone investigating linguistic challenges during emergency operations at nuclear power plants resonated with high-level stakeholder representatives and generated changes in regional outreach and engagement on nuclear safety, safeguards, and security topics. In addition, the capstone projects themselves increased the ability to inform decisions in regional nuclear energy infrastructure development efforts—and include the Gulf-region's voice in the broader, global nuclear energy discourse. Lastly, the mere fact that GNEII is referenced at all in the publications in the *GNEII-Related Literature data set* shows a strong and growing positive reputation of the institute. In this manner, GNEII is achieving its mission of supporting the responsible use of nuclear energy locally, regionally and globally.

This evidence supporting RQ2 provided a supplementary set of interesting insights. Here, GNEII's institutional impact is broad and varied—ranging across local (e.g., the use of the Fundamentals Course as an official step of "on-boarding" for UAE stakeholders), regional (e.g., regular requests for participation from across the greater Middle East region) and international (e.g., requests for assistance in replicating GNEII in other geographic areas) boundaries. In similar manner, the strategic (e.g., vision and mission) and tactical (e.g., three pillars and 3S-based pedagogy) multidisciplinary design decisions led to a larger positive institutional impact than originally envisioned. Lastly, and perhaps most clearly, GNEII's institutional impact is demonstrated best in its role in KU being named as the only *IAEA Collaborating Centre for Nuclear Energy Infrastructure and Human Resource Development* (for more, please see Alameri, et. al (2019)[22]). According to the IAEA, such collaborating centres are "scientific institutions such as laboratories, universities, research facilities, etc., that… have been designated to collaborate with the IAEA in a variety of fields, such as food safety, environmental protection, water resources and human health." Further, the pedagogical approach and list of topics provided in the GNEII Fundamentals Course is similar to more recent IAEA initiatives—namely the Nuclear Energy Management School (launched in 2010) and newly developed International Nuclear Management Academy (launched in 2013)—aimed at providing "managerial and technical competencies that are required to support national nuclear energy strategies" and "master's programmes with specialized focus on advanced aspects of management in nuclear technology, science and engineering," respectively. This suggests that GNEII was near the head of the curve on this holistic emphasis on nuclear infrastructure development—and its ability to implement a multidisciplinary, 3S-framework based curriculum.

Yet, these results are challenged by limitations within this study. Despite the admirable 31% survey response rate, these insights may not be truly representative across all past GNEII Fellows and this limits their applicability to future Fellows. The survey itself also could have been designed to include a larger number of questions that covered additional knowledge transfer (e.g., how has the knowledge you gained in the Fundamentals Course helped in you subsequent educational or professional development endeavors) and institutional impact (e.g., the extent to which my employer values GNEII-related knowledge or additional opportunities I pursued based on my knowledge from my GNEII experience) related questions. Likewise, the lack of additional *Course Evaluation data* (e.g., from the 2012 to 2015 classes) limits validity of the related analytical trends. Any future work to further this study should also include either surveys or interviews with representatives from regional nuclear energy program stakeholders to assess their perspective of GNEII's impact. (NOTE: A preliminary version of such analysis is offered in Williams, et. al (2016)[14] but needs to be expanded.)

Despite these limitations, GNEII has provided a high-performing, well-prepared cadre of early and mid-career professional to support regional nuclear energy programs; increased the quality and sophistication of its research efforts; and, grown into a Gulf and Middle East regional hub for addressing nuclear infrastructure and human capacity development needs. Sustainability and future plans are in development and will include crafting a modularized academic program accredited by federal UAE authorities; expanding collaborative research projects with institute stakeholders; and, growing the institute's ability to provide technical services to meet short term, targeted needs by regional nuclear energy stakeholders. Similarly, longer-term sustainability efforts will focus on benchmarking GNEII's new modular technical degree curriculum with IAEA best practices and supporting KU in building new research capabilities to leverage recent national Emirati interested (and financial support) in research in specific technical areas .

Conclusions

GNEII demonstrates one option for successfully providing a multidisciplinary 3S curriculum in support of broader nuclear infrastructure development aims. As such, other initiatives could leverage the key lessons learned during GNEII's activities from 2011 to 2016, including (but not limited to): (1) appropriately scope the length of the program to adequately cover the breadth of necessary multidisciplinary topics; (2) include a version of the capstone requirement (as multidiscipline capstone projects result in more useful, evidence-based solutions to complex problems[23]); (3) develop and use a systems thinking-based carry-through framework or model; (4) appreciate (and actively seek) the complexity of geopolitical and professional diversity in the course participants; (5) leverage a wide range of subject matter experts; and, (6) the fundamental utility of a faculty coordinator to provide an anchor of stability throughout—and thread of consistency across multidisciplinary topics in—such a course. The results of this study indicating the successful implementation of a multidisciplinary education program preparing young professionals to operate responsible nuclear energy programs also support the claim that mixed methods approaches can be used to evaluate education programs that emphasize the importance of systems thinking to create socially responsible and technically prepared graduates to meet the challenges of a complex, global society.[24]

Though just one piece of a much larger, multi-faceted, multi-national and loosely coordinated effort to develop the needed human infrastructure for nascent nuclear energy programs

throughout the world, GNEII's activities between 2011 and 2016 illustrate significant local, regional, and global impacts. Locally, GNEII has advanced the UAE's quest to become a leader in responsible nuclear infrastructure development in the region. Regionally, the institute provided an enhanced, localized understanding of responsible nuclear energy programs (including safety, safeguards and security obligations) more conveniently located than commonly used alternatives in Europe or the U.S. Globally, GNEII gives the nuclear infrastructure development community a model for an education and research-based institute that addresses the "critical role of the curriculum in promoting interdisciplinary habits of mind and action' in building multidisciplinary competence"[25, p. 90] across nuclear energy safety, safeguards and security in regional contexts to improve both infrastructure and human capacity development. Finally, GNEII has proven capable of developing an internationally-knowledgeable, regional cadre of nuclear professionals who can engage with their peer groups to analyze and develop more useful solutions for complex safety, security and safeguards challenges to global nuclear energy expansion.

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