2018 ASEE Annual Conference & Exposition
June 24–27, 2018, Salt Palace Convention Center, Salt Lake City, UT
Paper ID #22430

Damascus, AK to Pyongyang, NK: Developing an Entrepreneurial Mindset by Connecting Nuclear Weapons Safety, Chemical Process Safety and Global Politics

Dr. David DiBiasio, Worcester Polytechnic Institute

David DiBiasio is Associate Professor of Chemical Engineering and Department Head of ChE at WPI. He received his ChE degrees from Purdue University, worked for the DuPont Co, and has been at WPI since 1980. His current interests are in educational research: the process of student learning, international engineering education, and educational assessment. Collaboration with two colleagues resulted in being awarded the 2001 William Corcoran Award from Chemical Engineering Education. He served as 2004 chair of the ASEE ChE Division, has served as an ABET program evaluator and on the AIChE/ABET Education & Accreditation Committee. He has also served as Assessment Coordinator in WPI's Interdisciplinary and Global Studies Division and as Director of WPI's Washington DC Project Center. He was secretary/treasurer of the new Education Division of AIChE. In 2009 he was awarded the rank of Fellow in the ASEE, and in 2013 was awarded the rank of Fellow in AIChE.

Dr. Kristin Boudreau, Worcester Polytechnic Institute

Kristin Boudreau is Paris Fletcher Distinguished Professor of Humanities at Worcester Polytechnic Institute, where she also serves as Head of the Department of Humanities and Arts. Her training is in nineteenth-century literature, but for the past 9 years she has taught engineering ethics, first-year engineering courses, and humanities for engineers. She has also worked with students and colleagues to develop role-playing games teaching engineering within its complex humanistic context.

NOTE: this paper has co-authors.

Dr. Leslie Dodson, Worcester Polytechnic Institute

Leslie Dodson is a Faculty Teaching Fellow in Undergraduate Studies at WPI. She received her PhD from the University of Colorado-Boulder's College of Engineering and Applied Science, ATLAS Institute. Her current research interests focus on the intersections of international development, human-centered design and participatory community development. Specifically, Leslie leads research efforts on the world's largest fog water harvesting system in rural, Berber communities in southwest Morocco. She also has expertise in alternative pedagogical methods such as immersive, embodied and engaged learning. Leslie is a Visiting Scholar at the University of Colorado-Boulder Center for Science and Technology Policy Research. Prior to her work in academia, she was an international correspondent and producer for CNBC, MSNBC, CNN, NHK-Tokyo and Reuters Financial Television covering the global financial markets, environmental issues and international relations.

Dr. Curtis Abel, Worcester Polytechnic Institute

Damascus, AK to Pyongyang, NK: Developing Entrepreneurial Mindset by Connecting Nuclear Weapons Safety, Chemical Process Safety and Global Politics

Developing entrepreneurial mindset learning (EML) in engineering education challenges instructors to implement learning activities that promote student learning in three key areas: creative and critical thinking (curiosity), minimizing segmented learning (making connections among apparently unrelated concepts), and including human/social considerations in engineering analysis (value creation). The Kern Family Foundation has catalyzed EML implementation in engineering education by partnering with several universities (http://www.kffdn.org/) through a collaborative called the Kern Entrepreneurial Engineering Network (http://www.kffdn.org/). Worcester Polytechnic Institute is one of the participating institutions that, through a multi-year grant, are developing curricular innovations that bring EML to courses in all the engineering departments over all four years of students' academic careers. In chemical engineering, approximately ¾ of our faculty are involved in developing, implementing, and evaluating EML modules in multiple courses throughout our curriculum.

Entrepreneurial mindset is not restricted to the traditional perception of entrepreneurship that typically means raising venture capital to fund start-ups based upon patentable or other new technology. Instead, it is a much broader approach that challenges students to engage in the "3 C's" (curiosity, connections, and creating value). EML is an excellent complement to project-based learning, collaborative pedagogies, and other student-centered activities both in and out of class. The KEEN framework is summarized in Figure 1.

In this paper we describe a unique project that was implemented in the first course in chemical engineering (material and energy balances). We used the 1980 Titan missile accident in Damascus, AK as a focal point. Our EML module included basic mass balance analysis put in an historical context but extended to include a qualitative chemical process accident case study, and to analysis of present day tensions between the US and North Korea. The multidisciplinary and unique nature of this project required careful preparation and construction of the student assignment. Hence, the primary author recruited the help of colleagues with expertise in social science, humanities and arts, and innovation/entrepreneurship to help design the entire assignment and the assessment. Kris Boudreau is Head of WPI's Humanities and Arts Department, with a PhD in American Literature and current scholarly interests in infusing liberal arts into engineering education including developing our Humanitarian Engineering courses. Leslie Dodson, PhD in Technology, Society and Media, teaches Humanitarian Engineering and is involved with WPI's KEEN project and global studies. Curtis Abel, PhD in Materials Science and Engineering, is Professor of Practice in Innovation and Entrepreneurship at WPI, also involved in KEEN and Humanitarian Engineering. Although DiBiasio did the calculation details, the entire team was involved in developing all aspects of the rest of the project including questions and prompts shown in the box below, project organization, and assessment survey prompts and analysis.

The module was a team-based project imbedded in the traditional sophomore year introductory ChE course. We implemented the module in a class of 94 students in the first fall quarter of the 2017-18 academic year. The basis of the project was the PBS American Experience documentary *Command and Control: The Unknown Story of the Day Our Luck Almost Ran Out* (R. Kenner, Director and from the book by E. Schlosser, (2)). The film provides a realistic visual recreation of the accident and describes events that ultimately led to the explosion in the Damascus, AK Titan missile silo. Through archival documents and interviews with workers, residents near the facility, law enforcement personnel, nuclear weapons experts, military personnel, and the then Secretary of Defense, viewers are led through the complete

Figure 1. Conceptual Summary of Entrepreneurial Mindset (1)

event timeline. The accident serves as a focal point for presenting Schlosser's description of the state of nuclear weapons safety during the cold war.

The accident started with the simple dropping of a ratchet that penetrated the rocket hull causing a fuel leak that spiraled into a major event resulting in 21 injuries and 1 fatality. The explosion destroyed a multi-million dollar Titan missile silo and rocket -- at the time the largest missile in the American arsenal. The silo, approximately 50 ft in diameter, extended more than seven stories underground. The missile was meant to deliver a nine-megaton warhead (see Figure 2). Detonation of that warhead would have destroyed everything within a several mile radius and resulted in millions of lives lost from both the explosion and subsequent radiation. Fortunately the nuclear warhead did not detonate, but the event was not an isolated one and served as an example of nuclear weapons safety problems in the US.

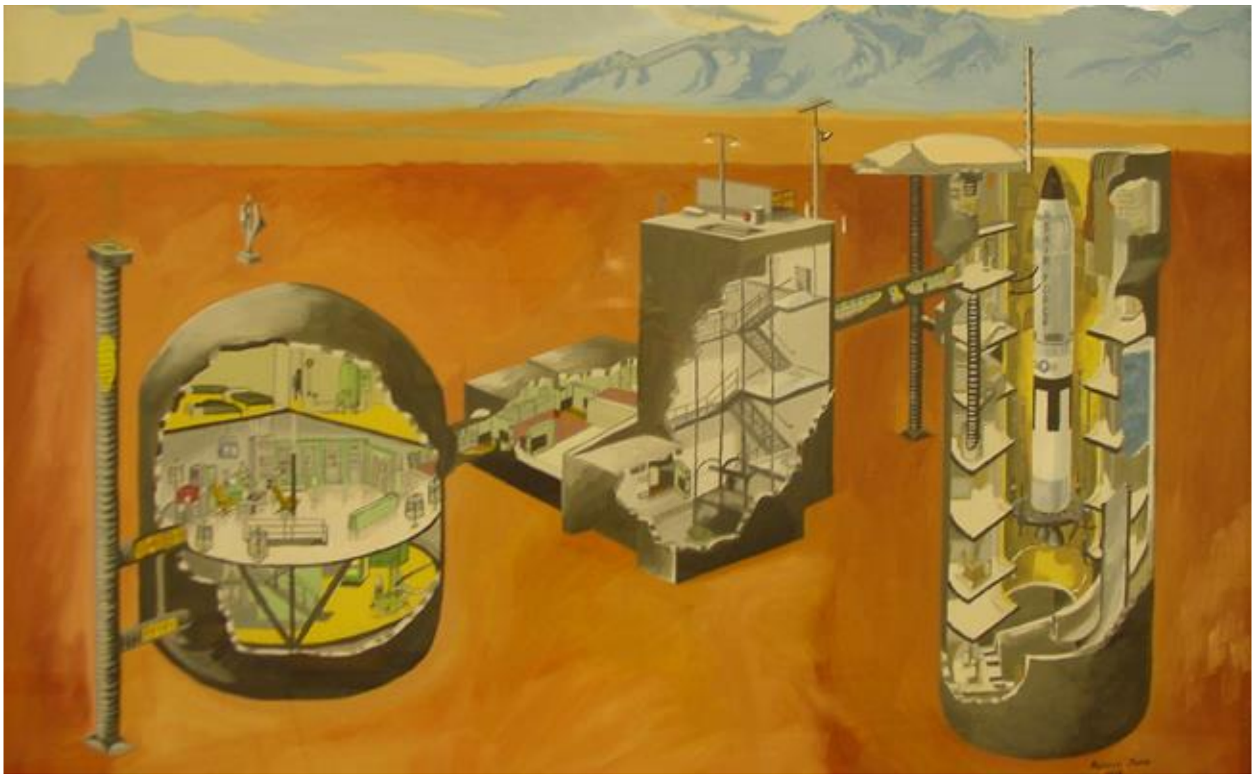

Figure 2: Schematic of Titan missile complex (3)

The connections between a missile accident and basic ChE topics might at first appear weak. However, there are three areas appropriate for new ChE students. These include using the fuel leak to introduce non-steady state mass balance concepts, examining parallels with recent chemical process accidents, and introducing risk-consequence models to promote informed discussion about current political NK-US debates. In the paper we describe the project details including the mass balance analysis, the process safety case studies (each team chose their own comparison incident), and the risk model discussions. We'll also demonstrate the EML elements using student work samples.

The course is the first sophomore-level course in a 4-course, integrated sequence. This introductory course covers basic material and energy balances, thermodynamics, and an introduction to vapor-liquid equilibrium and separations. Normally content is restricted to steady state mass balances in single and multiple units. Typically non-steady state balances are covered only qualitatively with maybe one quantitative example. So in addition to engaging a somewhat different concept for engineering analysis we decided to challenge the students by having them use the transient balance to analyze the fuel leak scenario. Educational goals included having students solve and interpret the results from a transient balance from an unusual process (*connections*), learn about chemical process safety via case study (*curiosity and connections*), and apply, where appropriate, that learning to current politics (*connections and value creation*).

Students were randomly assigned to teams for this project and the module was broken down into four parts:

1. Watch the documentary *Command and Control (4).*
2. Analyze a simplified representation of the fuel leak including a mass balance around the silo.
3. Compare the Titan accident to a contemporary chemical process incident.
4. Extend the above work to an investigation of the current tensions between North Korea and the US.

The text box below presents relevant excerpts from the assignment. Student teams had about a 2.5 weeks period to complete the assignment and submit a formal written report, including mass balance calculations, to the instructor. We provided a simplified transient species balance for the fuel leak in symbolic form since students had not had much experience in writing such balances. Teams had to identify values for all terms and properly integrate the equation to calculate the requested numbers.

Our assessment of the EML project included three elements that we address separately:

- Anecdotal evidence from student questions and team visits to DiBiasio's office.
- Detailed reading and grading of the final reports.
- Textual analysis of an end-of-course, open-ended survey.

<u>Anecdotal evidence.</u> Although not all teams took advantage of office hours and other opportunities to contact the instructor, a representative sample did. It became clear that although we provided students with the proper transient balance equation that had an accumulation term, many had trouble realizing they needed to integrate the equation or they attempted some type of simple, but incorrect, integration. An important *connection* was not made between calculus and chemical engineering. This surprised the ChE instructor, particularly the fact that many students did not realize they could simply look up the integrated solution online or in a textbook. We believe the solution to this is to do more class examples and homework on simple transient balances (like tank filling or solute mixing) prior to introducing the project.

<u>Final Reports.</u> Review of the 25 team reports showed them to all be very good to excellent. This was a pleasant surprise to the ChE instructor who has been doing course projects for many years in this and similar classes. Typically there are teams whose dysfunction results in a poor report or who are simply unmotivated and do not demonstrate the effort needed to produce good quality work. This was not the case with this project. There were no grades below a B and 20 teams earned an A or A-. We'd like to

think that the unique content engaged students more than the traditional topics used in previous projects, and student surveys helped us understand how. This is discussed in detail below in the survey section.

A. Fuel Leak Dynamics. The accident at the Damascus, Arkansas site involved a complex series of events that ultimately resulted in the explosion. We cannot fully analyze the mass balance, chemical reaction hazards, and process dynamics due to a lack of detailed information and because the ChE content knowledge required is beyond where we are at this point in the term. However, we can do an approximate analysis that will highlight the kind of quantitative analysis that is useful during an accident scenario. We'll look at the process dynamics by estimating the time it would take from initiation of the fuel leak to when the environment in the silo just reaches the lower explosive limit (LEL). Your team will calculate that time based upon the following conditions. Use the species balance to estimate the time it will take to reach the LEL. This represents the time available for those present to decide upon a course of action. Imagine a fictional scenario in which your team is the engineering group in charge. Based upon your analysis, is there enough time to take action? If so, what might have been your recommendations? What protocols or other actions should have been modified or put in place, or controls installed to minimize consequences of a fuel leak and possibly prevent an explosion?

B. Comparison to Chemical Process Scenario. Search the literature for a contemporary chemical process accident. Avoid the more infamous accidents (like Bhopal and Flixborough) and use one from the US. The US Chemical Safety Board home page is an excellent resource under the "completed investigations" link. Select one example to compare to the Damascus incident. Submit your selection to Prof. DiBiasio for review before proceeding further with this part. Once your scenario is chosen and approved, compare and contrast the Damascus incident to your chemical process example. Discuss similarities and differences. Be sure to include the technical aspects of both in addition to the actions taken by those involved and how they affected subsequent events. In either incident, were there times when a flexible human-focused interpretation of rules and protocols might have an advantage over strict adherence to checklists?

C. Current Events. Currently the US and North Korea are in an ideological conflict that could have grave consequences. Certainly, the deliberate deployment of a nuclear weapon will have serious negative effects on millions of people. However, an accident might trigger a similar result. Given the film's point of view and your critical analysis of the film, how much attention and resources should be allocated to preventing such an accident? What is the likelihood of a nuclear weapons accident anywhere in the world today compared to that of a chemical plant? Consider a simplified risk/consequence model and provide documentation and/or evidence for your discussion. Finally, If your team had unlimited authority and could make one recommendation to any person or agency in the world, what would it be and why?

Nearly all teams eventually figured out the mass balance that showed, similar to the real accident, that about 8-9 hours would elapse before the LEL was reached and an explosion was imminent. They used their results to discuss what steps in the communication chain might have been improved, what actions might have been taken prior to or during the accident to mitigate damage or prevent explosion, and how future incidents in similar missile units might be prevented.

Teams chose a wide variety of documented chemical process safety incidents to compare and contrast. Nearly all cases came from the Chemical Safety Board site so this introduced students to the CSB and got them to read CSB reports and view accident-recreating animations. Cases ranged from more well-known accidents like the Deepwater Horizon to those like the recent flooding problem at the Arkema plant in Texas. Comparisons were thoughtful and typically pointed out important and relevant similarities and differences. It was clear to the instructor that teams provided substantial evidence for their ability to realize the complexity of chemical processes and that even with redundant protection measures, the interactions of people with each other and with large integrated systems frequently is the most important thing during a safety incident.

We expected that the discussion about North Korea, the US, and current nuclear tensions might be a challenging connection to make (part C). However, the instructor thought it important to raise students' level of consciousness about weapons safety and possible warfare. Again, reports demonstrated that students took this seriously and were able to use a simple risk-consequence model (5) to provide meaningful and interesting analyses. The model presented in class is similar to that shown in Figure 3.

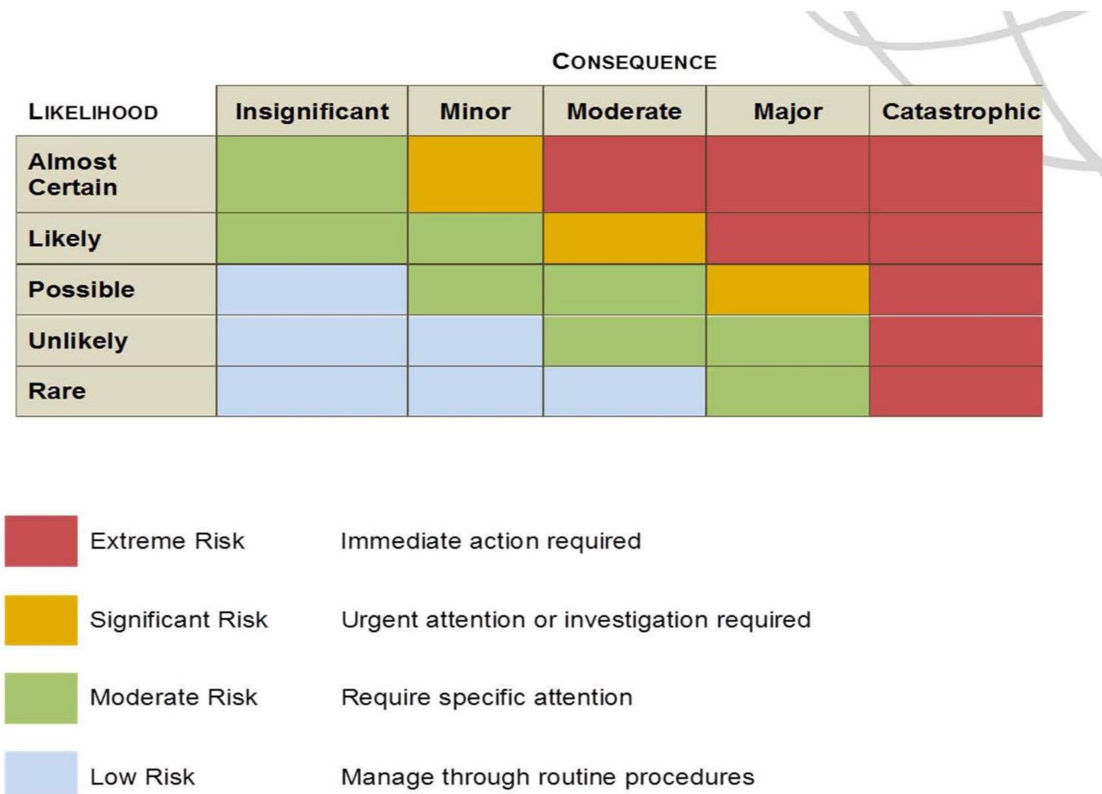

Figure 3: Simple risk-consequence model, taken from (5).

Expectations were that students discuss weighing the likelihood of a nuclear accident against consequences and the cost of implementing protective/preventive measures. For the most part these discussions achieved expectations. Some teams provided arguments typical of the cold war "mutually assured destruction" approach, while others discussed the benefits of de-escalation and the banning of nuclear weapons. Fortunately, no team presented a case for a pre-emptive strike on North Korea. In many cases, there was some sense that despite accidents in the nuclear weapons industry in the US, and that no warhead has been detonated, perhaps as a country we've evolved better controls and safeguards.

In one case a team provided a well-constructed argument that posited nuclear weapons safety might be better in NK despite our preconceptions that it be worse than the US due to secrecy and lack of resources. Their argument was that NK's position of power in the world depends largely on their military threats. An accident would be physically devastating but would also result in a significant loss of face and fear in the eyes of their neighboring countries and probably throughout the world. Hence they can't really afford to suffer an accident or easily recover from the result of one.

<u>End of project survey</u>. We implemented an open-ended survey near the end of the course. The survey had four prompts:

1. Describe, in general, your thoughts/opinions about the connections among the Titan accident, your chemical process incident and current NK-US politics.

2. Did the project cause you to think differently or want to learn more about chemical process safety and nuclear weapons issues? Why/why not?

3. Engineers frequently focus on creating value when designing or analyzing products and processes. In your opinion, what were the value creation aspects of this project?

4. Any other general comments are welcome.

We received 81 completed surveys for a response rate of 86%. Two of us analyzed the written responses by agreeing on a coding scheme that we verified by reviewing several responses. We then established a simplified rubric for each prompt that we tested together by rating a few responses. We then individually rated the same 15 surveys and reconvened to complete the inter-rate calibration. Finally, we separately rated all 86 surveys, met to resolve any differences, and finalized our results.

It should be noted that the instructor did not repeatedly discuss the 3 C's language of EML during the course. It was described in the syllabus but not explicitly referenced after that. The reason was to see if student work would show evidence of the 3 C's without being told directly. In other words we wanted to avoid hearing "yes I was curious" simply because we told them to be curious. Clearly the first three prompts involved the C's. The results are summarized below with the caveat that responses don't always sum to 81 because they were either left blank or were unreadable.

<u>Connections (1)</u>: Forty responses exhibited a strong or moderate understanding of specific connections while another 40 showed none. Evidence for understanding included specific mention of events, principles, or concepts among the three topics while a rating of no understanding was typified by responses such as "I was able to see the connections between the Titan accident and the T2 plant

explosion but not with North Korea". Given the strength of the final reports in this area a 50% result was a bit disappointing. There may be several reasons. One is that one or two team members, who saw significant connections, were responsible for most of the report writing. Another is that the prompt itself needs improvement. In the next course offering it will read "Explain the connections . . . "

Curiosity (2): Sixty-six responded positively to this prompt while only 14 did not. While this was encouraging, several responses (positive and negative) expressed concern about their choice of major and the dangers of chemical processes.

> "The project made me nervous to become a chemical engineer . . "
>
> "The project implanted a fear in me . . . . made me second-guess my choice to be a chemical engineering major."

While educating students about process safety is very important the instructor has always worried a bit that too much, too soon, might be a problem. However, sheltering students from the consequences of bad engineering, improper design, and failure to include the human component in their analyses is not the preferred approach. After some discussion among the authors and others involved in teaching our sophomores we held a special session in a follow-on ChE class to address these issues. Two ChE faculty not associated with this project and two of the authors (outside of ChE) facilitated a presentation and discussion among all the ChE sophomores. We addressed topics such as the relative safety of the chemical industry, and the importance of understanding consequence, conducting a rigorous risk analysis, making informed career decisions, and the need for including human aspects with their technical work. We did not do a formal evaluation of the session but our sense was that it was successful in providing closure and addressing some of concerns we saw in the surveys. The students who spoke up during this session seemed interested in thinking ahead about the kinds of work environments they might enter and the extent to which they could choose jobs in the field of chemical engineering that were compatible with their values.

Value Creation (3): This prompt resulted in an interesting and unpredicted set of responses. The ChE instructor expected to see most responses be something like "*this project values the safety of others*", but that was not the case. Thirty-five responses discussed what we labeled "internal" value or value to the student. Typical internal type responses were those like "*I learned how to solve a problem that seemed too difficult*" or "*completing a real world project like this was valuable*". Twenty students described "external" (or societal) value such as "*learning to prevent accidents is valuable because lives and expensive equipment need to be protected*". Eleven students mentioned both types. So despite being a bit of a surprise overall these results were quite encouraging.

Student Engagement: As a gateway course to the major, this sophomore-level class has two broad goals: to help students master important chemical engineering content and to retain their interest in the discipline. The trick is to develop assignments that challenge students to develop disciplinary knowledge while engaging them in the big questions of the field. We wanted to encourage deep rather than surface learning, so that students are intrinsically motivated —that is, driven by the desire to master the subject of chemical engineering rather than by grades. Theorists of learning have identified four elements of student motivation: *competence*, *autonomy* (6), *relatedness* (7), and *purpose* (8).

Although we did not prompt students specifically about their motivation, the open-ended nature of our survey elicited responses that suggest that many students found the assignment motivating. Several responses indicated some of the four elements of intrinsic student motivation. Below, we describe each element, illustrating it with representative excerpts from the student surveys.

Deci and Flaste (1995) note that "The strivings for competence and autonomy together—propelled by curiosity and interests—are … complementary growth forces that lead people to become increasingly accomplished and to go on learning throughout their lifetimes."

- Several students noted the power of **autonomy,** or the power to define some part of an assignment rather than simply answering questions set by the professor:

  "the project brought together a group of people, and made them accountable to complete a project in the way they deemed fit."

  "The project was a good one and allowed for students to use a variety of different thinking skills to solve numerous problems."

- The assignment presented students with a sense of **purpose.** In the words of one student:

  "It helped us see the situation from more of an insider's perspective. I was aware that it happened but while doing the calculations I felt like I was involved in helping to stop the explosion."

- Another motivator is **Relatedness,** or putting students in relationship to other people. This student pointed out the importance of working on a project team:

  "I got to complete a group project while beginning my first steps as a chemical engineer."

- Finally, **competence** develops when the instructor sets a very high standard and gives students the support they need to reach it, so that when they complete the assignment they are struck with a sense of accomplishment and have more confidence for the next difficult assignment. Several students pointed to the need for more scaffolding or support in this assignment:

  "I found the most difficult part to be the material balance and how it isn't just something we could figure out on our own."

  "More guidance for the calculations."

In future iterations we will provide more support for this assignment. However, we were pleased to learn that students articulated the principle of competence in their surveys:

"I thought the project was tough but very rewarding."

"I thought this connection was cool because it demonstrated, in as soon as my first chemical engineering class, that we are already capable of applying the knowledge we learned in class to a real life situation."

Summary and Conclusion

In summary, our overall evaluation, including student work and student feedback, leads us to conclude that this EML module was a success. By connecting three potentially disparate topics (transient material balances, process and weapons safety, and nuclear politics) students produced surprisingly good work and seemed engaged and interested in the topics. We accomplished introducing a simple transient mass balance in a course where it is not normally taught. Student teams, on their own, investigated and wrote about chemical process safety case studies with intelligence and thoroughness. And, finally teams indicated through report writing and survey responses, an increased appreciation for and understanding of current nuclear politics and dangers.

Development of the EML module was not simple and the ChE instructor realized early on that help from colleagues outside the major was needed. This transdisciplinary approach to teaching is growing at WPI and is a natural consequence of our desire to engage students in complex issues and problems that cannot be solved by one type of expertise. The approach is also typical of the philosophy of learning at the core of the KEEN framework.

Acknowledgement

The authors are grateful to the Kern Family Foundation for funding providing support through our university's KEEN grant.

References

1. https://keenwarehouse.blob.core.windows.net/keen-downloads/KEEN_Framework_spread.pdf (accessed 2/4/18)

2. Schlosser, E. *Command and Control: Nuclear Weapons, the Damascus Accident, and the Illusion of Safety*, Penguin Books, 2013.

3. http://www.polarinertia.com/jan04/titan01.htm (accessed 2/4/18)

4. http://www.pbs.org/wgbh/americanexperience/films/command-and-control/ (accessed 2/4/18)

5. https://www.ajg.com/media/1697472/globalization-developing-your-international-risk-management-plan-pousson-zimmaro.pdf (accessed 2/4/18)

6. Deci, E. L., & Flaste, R. (1995). *Why we do what we do: The dynamics of personal autonomy*. New York: G P Putnam's Sons.

7. Ryan, R. M., and E.L. Deci. *Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions*, *Contemporary educational psychology* 25.1 (2000): 54-67.

8. Bruff, D. (2011) *An Introduction to Evidence-Based Undergraduate STEM Teaching*. Coursera.