Measuring the success of an educational program through box-and-arrow diagram: A case study of the Quantitative Microbial Risk Assessment Interdisciplinary Instructional Institute

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Dr. Jade Mitchell is an Assistant Professor in the Department of Biosystems and Agricultural Engineering at Michigan State University. She received her B.S. from the University of Pittsburgh in Civil and Environmental Engineering, M.S. in Civil Engineering and Ph.D. in Environmental Engineering from Drexel University. Dr. Mitchell is keenly interested in supporting environmental and human health decision making through the use of integrated risk and decision frameworks. Her work includes development of new frameworks, models and data sets toward this end. Dr. Mitchell has specific experience in quantitative microbial risk assessment (QMRA) and she conducted her graduate research under the multi-University, multi-disciplinary, Center for Advancing Microbial Risk Assessment (CAMRA), a jointly funded US EPA and DHS Center of Excellence. After joining MSU, she became affiliated with CAMRA as a principal investigator. Her lab conducts both computational risk modeling research and fundamental research. Her current work and future interests lie at the intersection of chemical and microbial stressors where understanding trade-offs, benefits and risks deviate from existing risk paradigms and require new data, tools and frameworks. Her future research goals include applications of risk-based decision making to water infrastructure management, and emerging hazards such as antibiotic resistance. She is managing editor and a developer of the QMRAwiki, an interactive, online tool for the QMRA community. Dr. Mitchell has also been involved in developing and teaching training workshops in QMRA for several years. She was recently awarded a nearly $1M grant from the National Institutes of Health to develop a new course, models and tools to support interdisciplinary engagement in QMRA.

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Abstract. Box and arrow diagrams are simple models that help students synthesize information pertaining to complex environmental systems and allow instructors to identify and address the misconceptions. These diagrams can also be used to evaluate the effectiveness of training, through collection of diagrams before and after instruction. Box-and-arrow diagrams were used to measure the success of the Quantitative Microbial Risk Assessment Interdisciplinary Instructional Institute (QMRA III) at Michigan State University. QMRA III is a one-and-a-half-week training program designed for advanced graduate students, post-doctoral fellows and early career professionals to assimilate scientific data and implement computer programs towards building a risk assessment for assuring safety and health goals. Each cohort of QMRA III consists of engineering, biological and social scientists with the goal of cross training. As part of the evaluation plan of the program, students were asked to construct a box-and-arrow diagram conveying a risk management plan involving the full range of biologic, economic, social, political, and cultural factors that impact risk during a pathogen exposure. Additionally, experts, professors and career professionals who were also the instructors in QMRA III, were asked to construct similar diagrams. This paper presents the results of the evaluation of the diagrams, and demonstrates how a simple tool, such as box-and-arrow diagram can be used to evaluate an interdisciplinary educational program with emphasis on the expansion of the participant's knowledge beyond their own discipline. Using this method, effectiveness of the program was assessed by comparing the participants' understanding before and after the workshop, and also by comparing participants' diagrams to those conveyed by the experts.

Introduction and Background

Quantitative microbial risk assessment (QMRA) is the process of applying risk assessment principles to quantify the risk associated with planned or actual exposure to infectious microbes (Haas et al., 1999). QMRA uses four stages to identify the risk: hazard identification, dose-response, exposure assessment, and risk characterization (Medema and Ashbolt, 2006). Hazard identification describes microorganism and associated diseases, whereas dose-response quantifies the relationship between dose and health outcomes. Exposure assessment looks into the pathway that lead to exposure and identifies the affected population. Finally, risk characterization combines the information from previous three stages to characterize the probability of an adverse health outcome with a description of the variability and uncertainty associated with these estimates. In 2009, the National Research Council published an update to the established paradigm in Science and Decisions. Figure 1 illustrates the risk assessment process and feedback between scoping and management from this document.

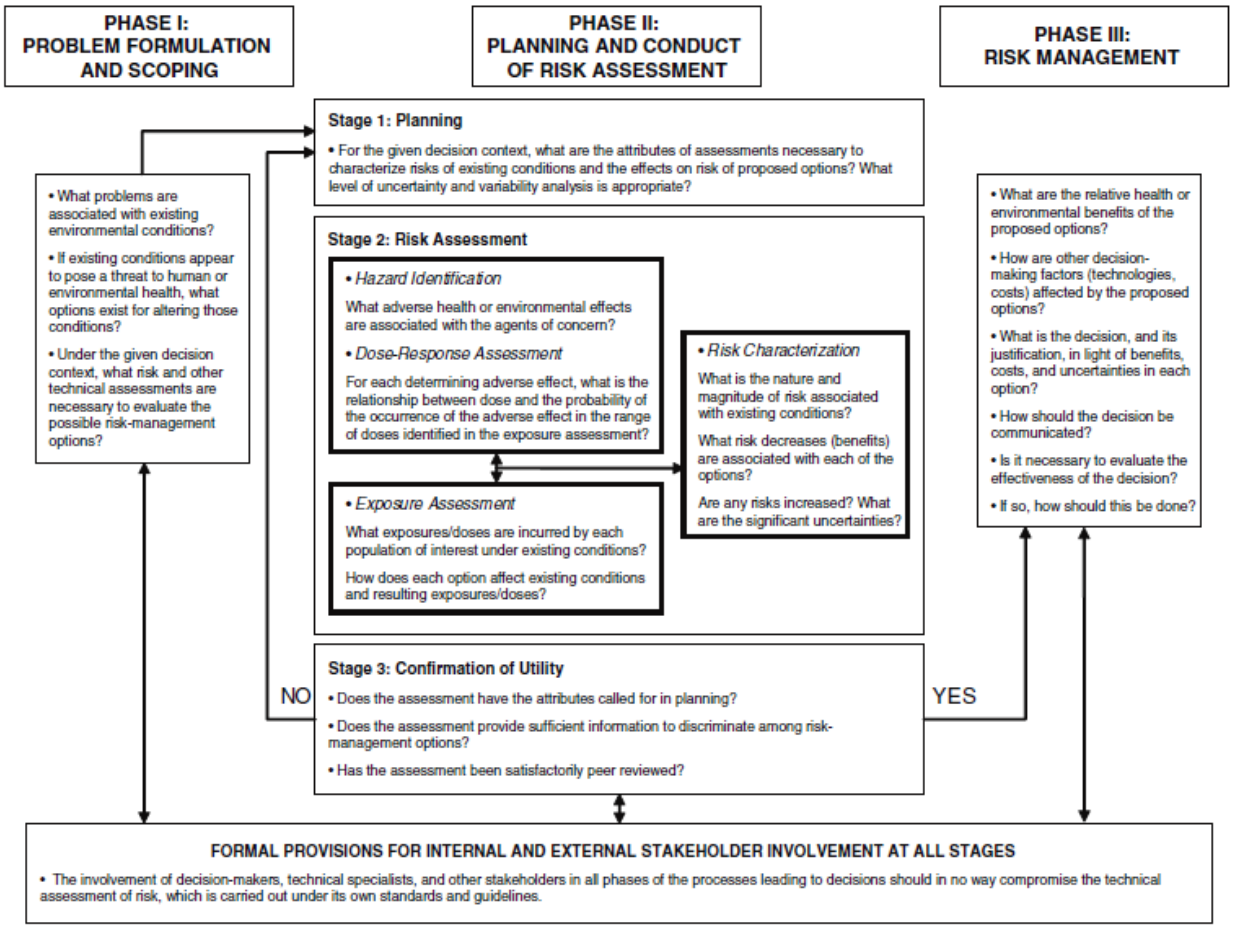

Figure 1. Risk Assessment Framework (NRC, 2009)

Microbial risk assessment is a scientific process that estimates the likelihood of microbial exposure and resulting public and environmental health impact (USDA and USEPA, 2012). Risk assessment framework is inextricably linked with other components of risk analysis which include risk management, risk communication, and other social as well as economic aspects. Figure 2 shows how these components are linked together.

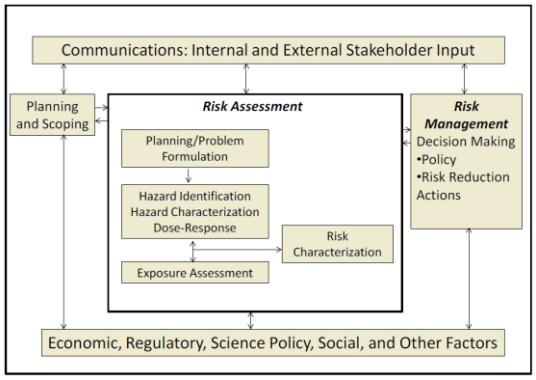

Figure 2. Risk assessment framework and its relationship with other components of risk analysis (USDA and USEPA, 2012)

A conceptual model describes or visualizes the relationships among various components so that readers get a clearer picture of risk assessment (USDA and USEPA, 2012). Figure 3 shows an example of a box-and-arrow conceptual model used to assess the risk associated with in-plant component of *Listeria*. The figure demonstrates that development of such a model is an iterative process and requires fitting each component into a large risk assessment framework. Hence, to construct such a conceptual model, one not only must understand the components of the risk assessment framework, but also know how they are linked with each other. QMRA approach is to recognize these interlinkages and follow the iterative process to come up with a management plan that brings the public/environmental health status to the target level.

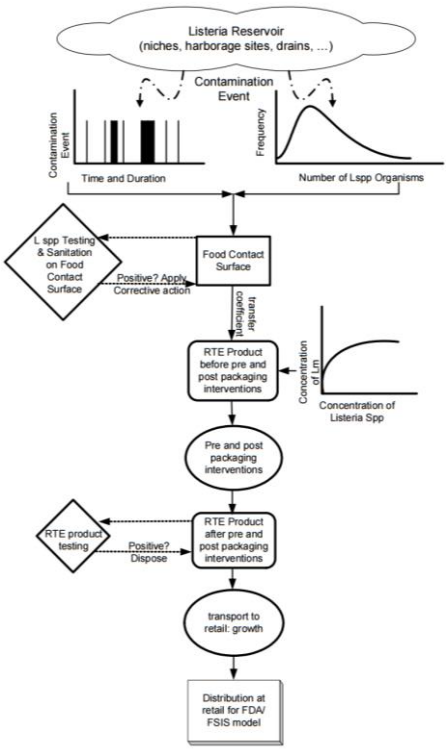

Figure 3. Conceptual model used to assess the risk associated with “in-plant” component of *Listeria* (USDA, 2003)

The Quantitative Microbial Risk Assessment Interdisciplinary Instructional Institute (QMRA III) is a 10-day workshop designed for advanced graduate students, post-doctoral fellows and early career professionals to assimilate scientific data and implement computer programs towards building a risk assessment for assuring safety and health goals. Participants gain hands-on experience with risk assessment software and work on real-world case studies. QMRAIII 2015 was conducted from 1st to 12th August 2015 at Michigan State University. PhD students, Master students, postdocs, early career faculty member and professionals participated in the program. A total of 32 participants, 15 females and 17 males, attended the workshop. Participants came from a diverse background, which included environmental science, environmental engineering, food science, microbial science, biosystems engineering and public health. Students submitted an application including a background survey and statement of their future research interests.

A box and arrow diagram is a method used to evaluate the student’s knowledge of the subject

matter pertaining to scientific understanding, which has been included in the Cause-Map method developed by Clark et al. (2009). Box-and-arrow diagrams are simple models that help students synthesize information pertaining to complex environmental systems and allow instructors to identify and rectify the misconceptions (Canham et al., 2003; Clark et al., 2009). Also, known as Cyclic Concept Maps, box-and-arrow diagrams are an appropriate tool in representing relationship between concepts (Safayeni et al., 2005). Box-and-arrow diagrams have been used in textbooks to explain the geological systems such as water and rock cycles at least since 1930s (Croneis and Krumbein, 1936). They are conceptual models, where boxes represent stocks and arrow represent the relationship between the stocks including flow and feedback. These diagrams can also be used to qualitatively measure how the understanding of an individual on certain subject matter changes over time. By qualitatively measuring the understanding of the participants on a subject matter before and after some educational program, these diagrams can be used to evaluate the outcome and effectiveness of an educational program.

This study seeks to understand the impact of the QMRAIII training model on participant understanding of microbial risk assessment and management using the box-and arrow method. More conventional survey instruments were also used to evaluate the effectiveness of the program as well, but this study focuses exclusively on the box-and-arrow diagram, which we believe provides a more holistic assessment of the participants' ability to conceptual the application of the complex risk assessment paradigm. In particular, we investigate the changing nature of mental models about risk management plans in the context of biologic, economic, social, political, and cultural factors.

Methods

Pre-workshop survey

To evaluate the effectiveness and measure the success of the workshop, participants were asked to complete a box-and-arrow diagram prior to the workshop. Participants were first provided with an example of box-and-arrow diagram that illustrated how the dirty dishes can become clean. Figure 4 shows the example provided to the participants. The boxes in the diagrams represented matter or energy or information and arrows represented processes that change or move that matter/energy/information.

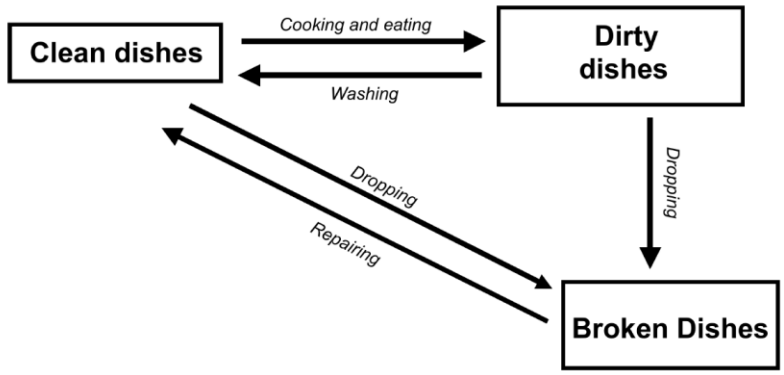

Figure 4. Example of the box-and-arrow diagram provided to the participants

Participants were then asked to construct their own box-and-arrow diagram showing a risk management plan during a pathogen exposure. Participants were asked to consider the full range of biologic, economic, social, political, and cultural factors while laying out their risk management plan. Figure 5 shows the question asked to the participants.

Please respond to the following question to the best of your ability.

1. You are tasked with providing a risk management plan that considers the full range of biologic, economic, social, political, and cultural factors that will impact risk during a pathogen exposure.
    a. **Please draw a boxes-and-arrows process diagram** laying out the different steps involved in developing your risk management plan.
        i. Place each step in a box.
        ii. Use a labeled arrow to represent processes.

Figure 5. Question asked to the participants prior to the QMRAIII workshop

The pre-workshop diagram constructed by the participants served as the benchmark of their knowledge on QMRA approach of risk management and their ability to communicate their understanding in a succinct form.

The QMRAIII workshop

Sixteen scientists/professors from 9 institutes from the USA and The Netherlands delivered lectures as well as laboratory exercises that covered a wide aspect of microbial risk assessment. The lecture started with an introduction to the QMRA framework and included different aspects of QMRA approach and components. The QMRA components discussed included hazard identification; pathogen detection; fate and transport of pathogens in soil, water and fomites; disease transmission and uncertainty; exposure assessment; dose response modeling; risk assessment, perception, management and communication. Additionally, students were introduced to a number of case studies pertaining to the QMRA approach of risk assessment and management. A number of lectures also included laboratory exercises where the participants had opportunities to gain hands-on experience from the experts. Finally, participants were assigned to five different case study groups, where the participants applied the QMRA approach to assess the microbial risk under real-world scenarios and formulated a management plan. On the final day of the workshop, students presented their case study findings and obtained feedback on their approach and results.

Post-workshop survey

The second part of the evaluation was conducted after the completion of the QMRAIII course work but prior to their final case study presentation. Participants were given the same instructions as the pre-workshop survey (Figure 2) and asked to draw a box-and-arrow diagram.

Evaluation

Box-and-arrow diagrams constructed by the participants were analyzed through two approaches. First, diagrams were scored following an approach by McNeal et al. (2014). In this approach, complexity of response is documented through analysis of the presence or absence of inputs,

outputs, processes, and feedbacks. Table 1 shows the rubric used for assigning complexity scores to the box and arrow diagrams. Closed loop were assigned higher points as the loops indicate that the developing a risk management process is an iterative process. The complexity scores from pre- and post-workshop survey were computed and compared for each participant. T-tests were run to compare pre- and post-workshop understanding.

Table 1. Coding Rubric for Box-and-Arrow Diagrams Complexity

Symbol	**Description**	**Points**
	Arrows (unidirectional or feedback)	1
	Boxes	2
	Closed Loop	3

Second, box-and-arrow diagrams were analyzed for their accuracy. In this approach, all the pre- and post-workshop survey diagrams were pooled together and rank ordered relative to their accuracy. Accuracy of the diagrams were determined through comparison to expert models. Figure 6 shows the aggregate model that was used for accuracy ranking and was formed by combing models from two experts.

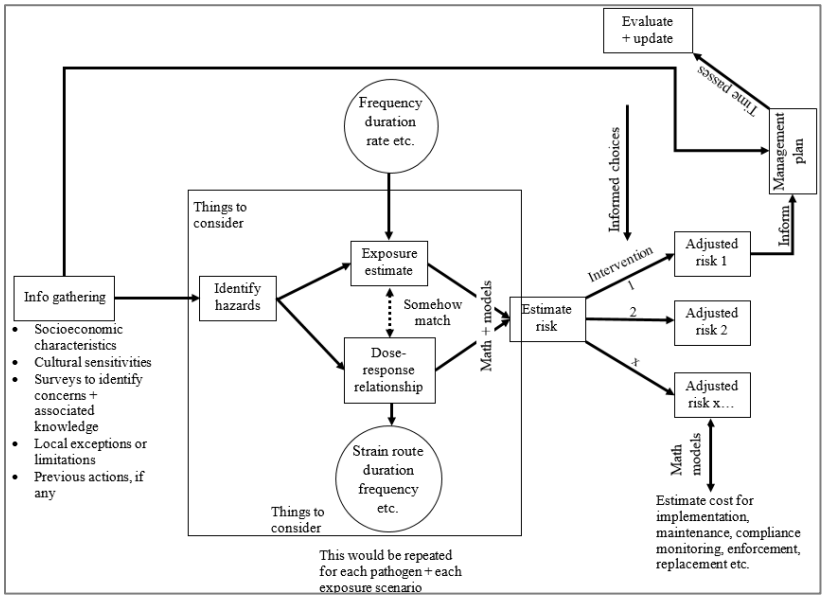

Figure 6. Expert models used in accuracy ranking

Findings and Discussion

QMRA III participants came from a diverse background. Figure 7 shows the result of the background survey from 24 applicants who eventually participated in the QMRA III workshop. Most of the participants (21 participants) rated their knowledge on epidemiology and risk analysis at 3 or lower. Relatively higher number of participants rated their knowledge on public health above 3 (9 participants). No student indicated previous experience in QMRA and most

were studying peripheral topics with the intention of applying the knowledge gained from their study into a risk assessment. Mitchell et al. (2017) has presented the detailed on specific components of the QMRA and the results of other assessment methods.

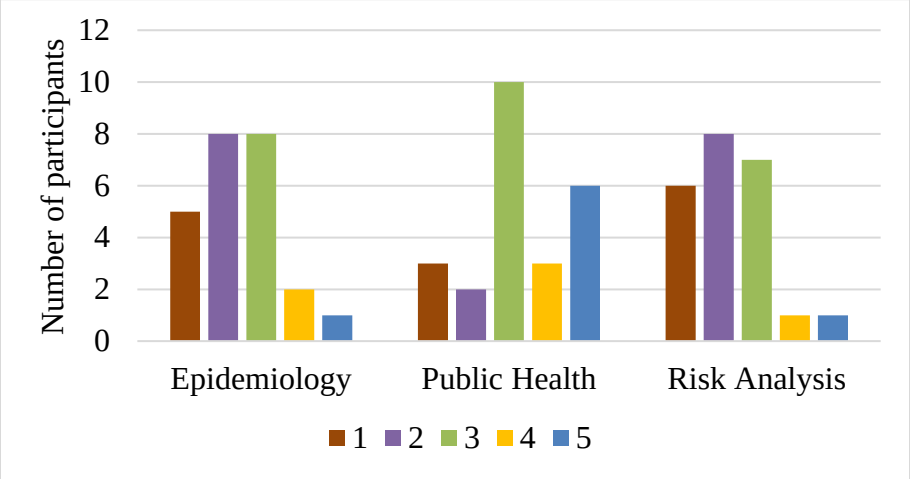

Figure 7. Participants' rating of their knowledge on epidemiology, public health and risk analysis on a scale of one to five

All the 32 participants completed the pre-workshop survey, while only 30 participants completed the post-workshop survey. To match the pre-and-post survey, participants were asked to write their e-mail addresses in their responses. Some of the participants did not write their email address and thus, their pre-and-post survey diagrams could not be matched. As a result, pre-and-post survey diagrams from only 24 participants could be matched and analyzed. Figure 8a and 8b show examples of the pre- and post-workshop diagram from a participant.

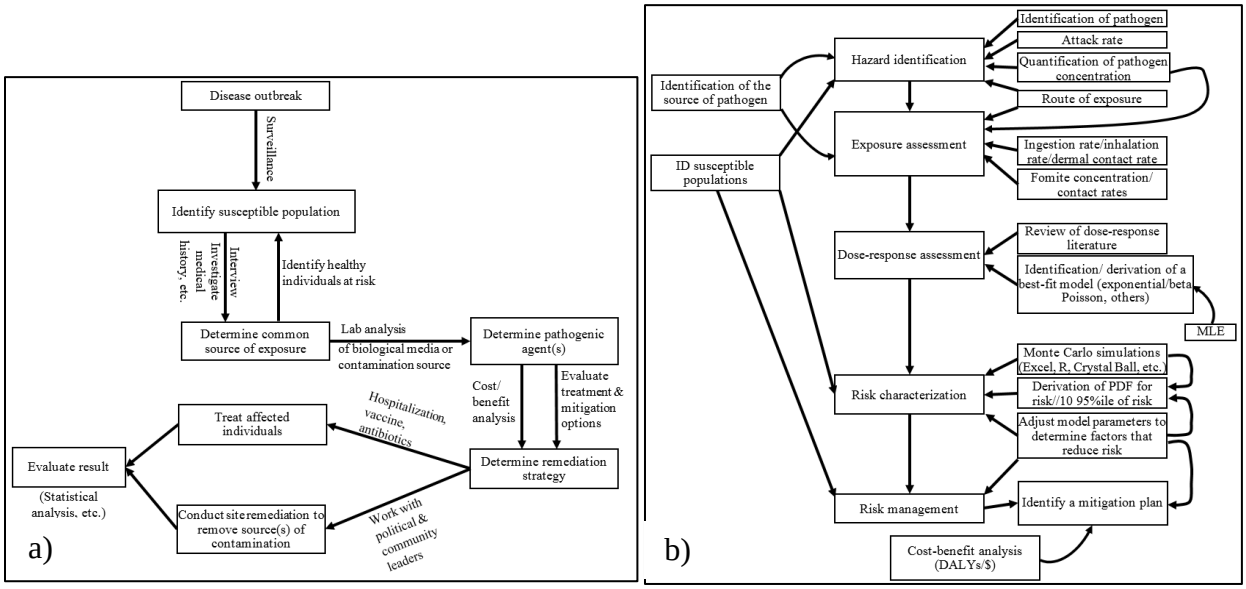

Figure 8. Example of the box-and-arrow diagram prior to (a) and after (b) the workshop (redrawn for clarity)

Figure 9 shows the average number of arrows, boxes and closed loops drawn by the participants prior to after the workshop. Average number of arrows increased from 8.3 to 9.0, while the average number of boxes increased from 7.2 to 8.5. However, average number of closed loops did not change.

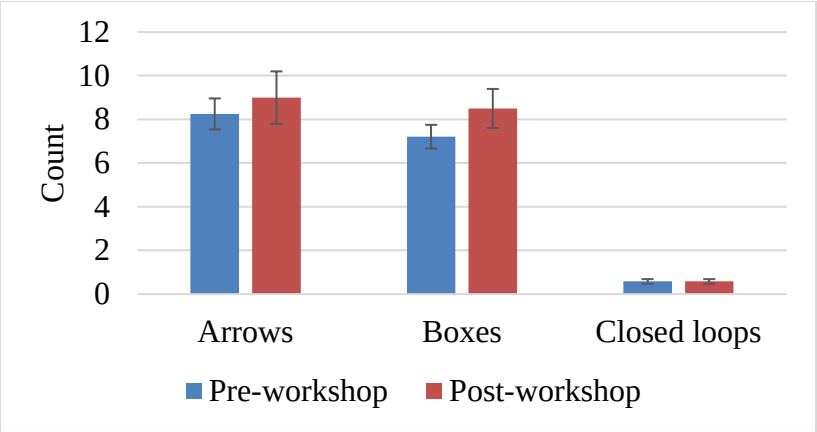

Figure 9. Average number of arrows, boxes and closed loops drawn by the participants prior and after the workshop (vertical lines show standard error)

Analysis showed that the complexity low scores were about the same for pre- and post-assessment, but post-assessment had much higher maximum scores. Average complexity of the pre-assessment drawings was 24.4±8.4, while average complexity of the post-assessment drawing was 28.2±16.7. This translate to an average increase from pre- to post- drawings of 4 complexity points, with a maximum increase of 55 points. Student t-test did not show a significant difference in total complexity points (p=0.114).

The least accurate drawings emerged from the pre-assessment and the most accurate drawings emerged from post-assessment. Average ranking, with a rank of 1 equating to the drawing that was closest to the expert model, of the pre-assessment drawing was 29.8±2.5, while average ranking of the post-assessment drawings was 19.2±2.8. Student t-test indicates that the average ranking of the post-assessment was significantly better than the pre-assessment ranking (p=0.004).

Overall, the QMRA III workshop appears to have increased understanding of the QMRA approach as well as recognition of the complexity involved in handling microbial risk management. Given that this workshop involves interdisciplinary scholars from biology, engineering, health, and environmental studies, the increase in understanding, both in terms of accuracy and recognition of complexity, is incredibly important and suggestive that workshops of this type are invaluable.

Conclusions and recommendations

This study measured the success of QMRA III workshop through the use of box-and-arrow diagrams. Before and after the QMRA III workshop, students were asked to draw box-and-arrow diagram showing a microbial risk management planed in a pathogen exposure scenario. The diagrams were evaluated for their complexity and accuracy. The results showed that the

workshop resulted in an average increase of 4 complexity point. Likewise, the students drew more accurate diagrams after the workshop, which resulted in better ranking. The overall improvement in understanding the QMRA approach is important for the participants that came from a diverse background. Moreover, results showed that the QMRA III workshop improved the participant's understanding of QMRA approach and that such workshops are invaluable in formulating microbial risk management plans during pathogen exposure. The results demonstrated that the box-and-arrow evaluation approach employed in this study has a potential to be applied to other settings to assess how an educational program changes participants understanding on pertaining subject matter.

This study only included the data from QMRA workshop that was held on 2015. In the future, box-and-arrow diagrams from two or more years will be analyzed for multiyear assessment. Furthermore, multiple experts will be asked to analyze the box and arrow diagram for their accuracy to minimize the biases. Future research will also consider the differential impacts of the QMRA III workshop on participants who come from different disciplines.

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