A Learning Science Protocol for Evaluation of a Sustainability-based Learning Environment

Eliot Rich, University at Albany <erich@albany.edu>
Reza Feyzi Behnagh, University at Albany <rfeyzibehnagh@albany.edu>
Babak Bahaddin, University at Albany <bbahaddin@albany.edu>
Mahdi M. Najafabadi, University at Albany <mnajafabadi@albany.edu>
Michael Deegan, US Army Corps of Engineers <Michael.A.Deegan@usace.army.mil>
Roderick MacDonald, University at Albany <rmacdonald@albany.edu>
Luis Luna-Reyes, University at Albany < lluna-reyes@albany.edu>
David F. Andersen, University at Albany <david.andersen@albany.edu>

Abstract

-- Everybody complains about the weather, but nobody does anything about it.
C.D. Warner, as quoted by Mark Twain.

The US National Research Council [1] observes that many of the scientific recommendations for coastal protection go unimplemented by local communities. What can be done to reify climate change effects for local decision-makers and stakeholders? Evidence-based climate models have not reached the level of resolution needed for detailed planning. Yet decisions made now (or deferred until later) will affect the economic resilience of thousands of coastal communities greatly.

Recently we developed a proposal for the implementation and field evaluation of a Simulation-Based Learning Environment (SBLE) in support of coastal protection planning. The project will adapt an existing classroom-based computer simulation [2] for use by local managers. It supports the design of a facilitated workshop activity where the lessons of the simulation are applied to the needs of each local community.

In this poster/paper we describe the context of the research, with particular interest in the learning science techniques to elicit the effects of the simulation on the perspectives of the participants, as well as identifying the factors that are important to public managers that may not be present in a classroom exercise. We look forward to an active conversation with conference participants about their own experiences in this area.

Introduction

Nowhere is the gap between science and public policy more patent than in the application of climate change insights to public decision-making [1]. Our vision is to take advantage of modeling and simulation to build the capacity of stakeholders and public managers to develop resilient communities and manage sustainability policy under the all-too-real conditions of environmental and scientific uncertainty, long delays between action and effect, and the need to work with multiple stakeholders and organizations in support of the public interest.

Computer-based simulations can provide stakeholders the mechanism to understand the effects of their actions and inactions on their sustainable future. When embedded in a constructed learning environment, computer simulation provides insights into fundamental lessons in management, the effects of complexity, and reasons for unanticipated outcomes [3]. The dissemination of these lessons in a convincing and scientifically grounded manner is an important leverage point to the identification of sustainable policies [4] and creating legitimacy for the challenging political process needed for their execution [5].

We have embarked on a multi-year project that focuses on the problem of coastal management as an exemplar of the sustainability challenge, where local managers make regulatory decisions and direct investment with partial knowledge about global climate pressures and incomplete scientific information. We will extend our existing simulation-based classroom experiments into a pilot program with local and regional managers identified by the US Army Corps of Engineers (USACE). Using the tools of Learning

Science we will evaluate and improve our simulation and teaching materials iteratively to better fit the needs of current and future public managers and stakeholders as well as establish the value of this approach to other complex sustainability problems.

Simulation-based interventions have been part of the SD literature for decades. Still, there appears to be a gap between the evaluation techniques used by modeling teams and those recommended by the learning sciences. This paper is part of an ongoing effort to find commonalities between common SD approaches and those of learning science.

Problem Domain

In 2005 Hurricane Katrina slammed into New Orleans with a death toll of 1,836 lives, a loss of 400,000 jobs, and a total cost to the US Economy of $110 billion. Again in 2012 Hurricane Sandy hit the New York/New Jersey region, at an expected cost of over $60 billion. These are just two instances of what may occur in a costly future; one privately-funded risk analysis projects that 6.5 million U.S. homes and $1.5 trillion of assets are at risk of damage from coastal storms [6]. Faced with the likely reoccurrence of these large-scale events, even small increases in the quality of the complex decision processes that support coastal protection decision making can yield very large future possible benefits in the form of avoided damages and citizen safety.

The ultimate cost of such storms depends on the quality, timing, and implementation of inter-governmental decision making involving community groups, state and federal agencies charged with long-range planning and emergency response. What can be done to increase community resilience in the face of climate emergencies? The answer goes beyond better climate modeling. While there is a strong scientific consensus about the increasing likelihood of extreme weather events throughout the United States, the downscaling of scientific climate models to local levels remains decades away [1]. Regional and local models require the integration of topological, physical and population data and interactions that are acceptably abstract in larger models.

Even when science is available, local and regional decision-makers have difficulty reaching consensus about how to apply climate information in a complex policy context [7]. The regulations and incentives needed to preserve community viability emerge as a negotiated result. As many of these regulations focus on the built environment, change may take many years to complete. For example, coastal managers may inadvertently increase long-term risks by encouraging construction and revitalization, particularly in the aftermath of a storm [8]. Successful protection rests with the use of scientific information by local communities about the short- and long-term effects of their range of actions.

Research Overview

Our research program looks to create a Simulation-Based Learning Environment (SBLE) to develop and disseminate the skills needed to promote community resilience under scientific uncertainty and systemic complexity. Over the past several years, researchers at the US Army Corps of Engineers (USACE) and the University at Albany have developed a simulation-based curriculum for a core modeling course in the MPA program at UAlbany [2]. The model is grounded in decades of experience in coastal protection within the USACE and is based on a USACE-sponsored study of approaches to redevelopment along the Mississippi coast after Hurricane Katrina struck in 2005 [9].

We propose to extend and refine our academic curriculum to the needs of local managers who make decisions regarding their own communities. The result of our efforts will be a scripted sustainability and resilience SBLE suited to workshop-based dissemination among broad academic and professional audiences. The workshop integrates systems thinking, climate science, and policy pressures, addressing concerns raised by climate scientists regarding the ability of managers to apply science well [1, 7]. We will evaluate the effectiveness of the SBLE on our student population and, with the cooperation of the

USACE, three panels of local sustainability and resilience managers. The SBLE will be available for the many communities facing coastal risks to explore options, understand the effects of the timing of their actions, and develop community consensus in support of sustainability and resilience.

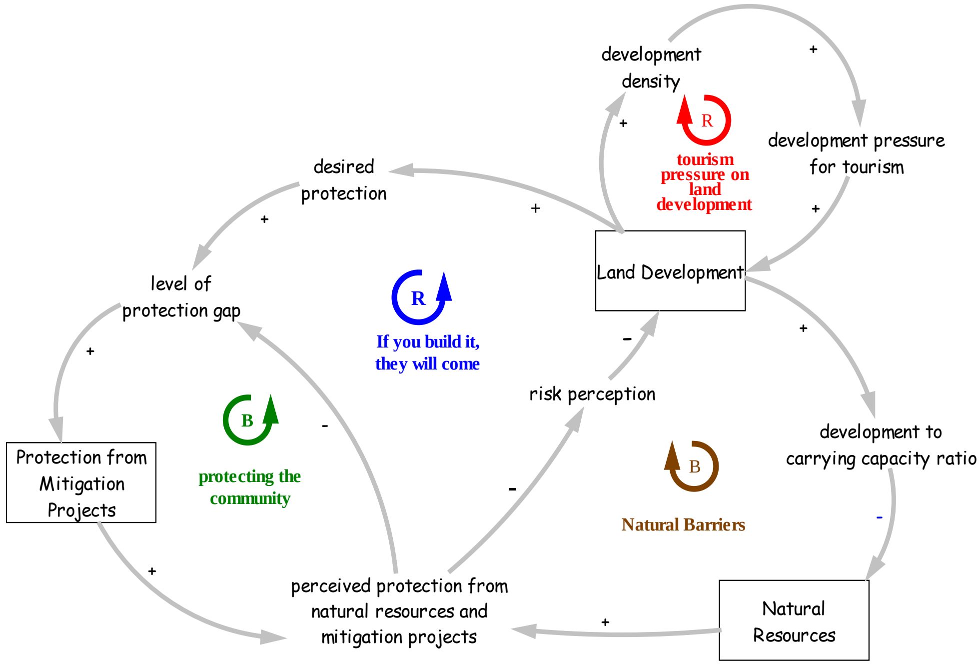
System Dynamics Group Model Building for Complex Problem Solving: Moving our classroom experience to the field requires recognition of the true decision contexts, where stakeholders work in complex and conflict-driven environments. Our team has deep expertise in the use of System Dynamics Group Model Building (SDGMB) to help groups collectively structure problems and identify and evaluate alternative policy options. We pair simulation modeling with group process methods to develop systemic problem-solving skills as well as strong relationships among group members. The process engages stakeholders in decision making by combining social facilitation with technical modeling to develop a shared view of the system structure generating the shared problem [10]. Substantial research supports the value of simulation-based group processes to manage social and technical complexity, improve the quality of group decisions and change the viewpoints and dynamics of interaction among participants [11] ;[12] [13], [14], [15],[16],[17].

Simulation-Based Learning Environments: Recent experimentation with generic and reusable simulation experiences that apply Learning Science based scaffolding have generated intriguing results that support their continued development and dissemination. A simulation-based learning environment is a teaching modality that combines facilitated discussion, curricular materials and computer programs that interactively model a system or a process [18]. SBLEs are based on the theory of learning as discovery or inquiry. Numerous advantages make SBLEs effective in helping students achieve better learning outcomes, including the ease of manipulating experimental variables, support of higher order thinking skills, testing student-generated hypotheses and predictions, identifying hidden causal relationships, and using multiple ways of representations to support understanding (e.g., texts, graphs, visualizations) [19]. Learning acquired by discovery and using of SBLEs is found to be retained longer and be more readily transferrable to other domains or tasks [20].

In addition to key factors outlined above, SBLEs foster discussion and collaboration for construction of knowledge and deep understanding about complex systems, in addition to providing for a more interesting, engaging, and motivating learning environment by having students solve authentic problems involving collaborative interactions [21]. Additionally, the computer and SBLE can foster learning processes such as co-regulation, shared regulation, and enhanced teamwork (e.g., aligning efforts, reaching consensus)[22]. SBLEs have been used extensively in teaching principles of system dynamics in environmental studies, as well as other domains [4], [23], [24]. However, there is still need for improvement in evaluating the impacts of SBLEs [25].

By emphasizing experience over explanation, SBLEs allow learners to accept a greater responsibility for their learning as they actively construct their own knowledge,[26] [27]. Experimenting with system variables and observing the effects facilitates a more active understanding about the system [28] [18] [29], [30]. Knowledge gained in this way is thought to be more elaborate and robust, and thus, not only more useful, but also more transferable to other domains.

Figure 1: Major Stocks and Feedback Loops in the *CoastalProtectSim* Simulation

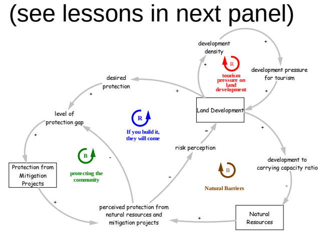


***CoastalProtectSim*: A Collaborative Activity of UAlbany and the US Army Corps of Engineers:** Beginning in the summer of 2010, the USACE partnered with faculty from the University at Albany to craft a curriculum on sustainability management and policies for a core modeling class in the MPA program. The core component of that curriculum is a system dynamics model as described by Deegan et al. [2]. The simulation runs with a gaming interface that allows users to interact with a policy menu to test policies such as building protective barriers and dikes, implementing more stringent building codes, creating zoning regulations to limit development of protected coastal areas, and pursuing policies that encourage the regeneration of natural resources that protect coastal regions (such as wetlands and tidal marshes). The simulation runs over a 50-year time span and users can vary assumptions about the long-term impacts of global climate change, both in terms of sea level rise and increases in storm intensity. The curriculum and its organization are described in detail by Ku et al. [31].

Figure 1 presents the major feedback structure of the model. It portrays interactions between four basic feedback processes organized around three long-term accumulations—(1) Land developed for tourism, housing, and commercial development, (2) Natural Resources such as wetlands and sandbars that are eroded by long-term pressures from development, and (3) Protective investments in dikes and other protective mitigation projects to increase community safety. The simulator gives users a tool to explore how the dynamics arising from these stocks and feedback structures play out over time in the presence of various policy interventions. In a workshop context, the participants transfer these explorations to their own localized concerns and community issues.

Systems-Based Lessons for Sustainable Coastal Protection: Table 1 presents an incomplete hierarchy of systems-based lessons for sustainable coastal protection based on three fundamental constructs in systems thinking shown in the top row [32]. The second row in Table 1 articulates general system lessons that apply to all systems being studied using system dynamics. The third row illustrates what we believe are some teachable lessons in the general domain of managing sustainable systems. The fourth row applies these lessons to the context of coastal protection. For example, under the column “Stocks as System building Blocks”, the second row notes the generic importance of this principle for all systems, the third row names three classes of stocks that interact in the management of sustainable systems, and the final row proposes what stocks need to be modeled and understood in the specific domain of coastal protection. As discussed further below, correctly filling in and "getting right" this proposed hierarchy of lessons for managing sustainable systems (with a specific emphasis on coastal protection) is the key task of Aim 1 of our research.

Table 1. Three Systems-Based Lessons for Sustainable Coastal Protection

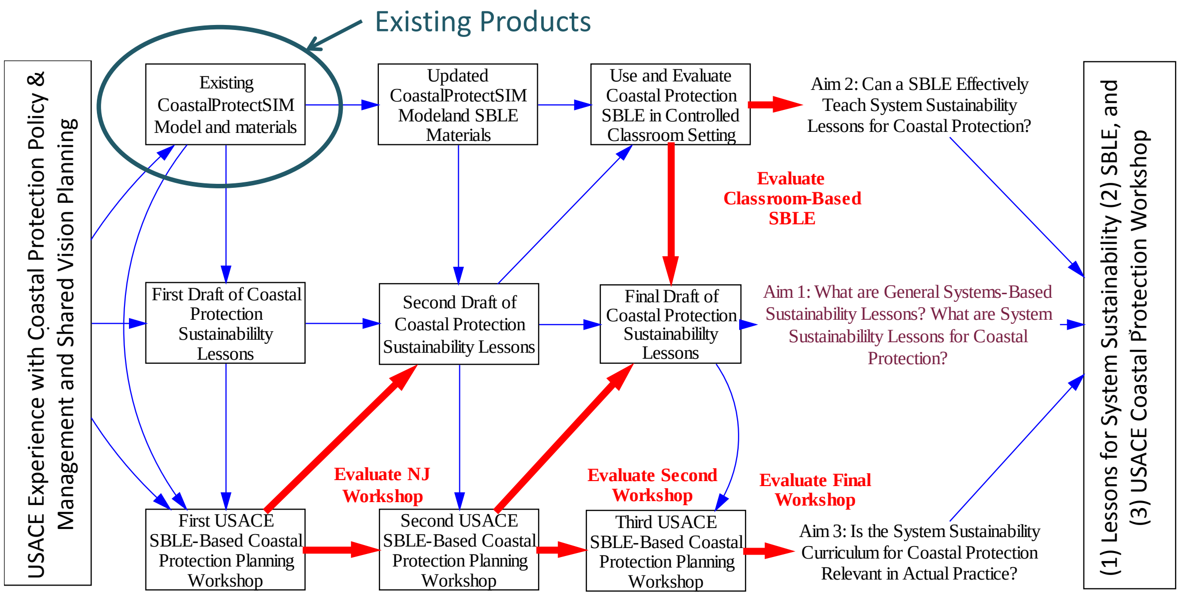
Principle or Lesson	Stocks as System Building Blocks	Feedback Drives Behavior	Endogenous Point of View
System Dynamics Lessons and Principles	Several key system stocks are fundamental building blocks	Feedback between stocks and flows in a system is the basis of a system's behavior over time.	Aspects of a system's behavior can be understood as the result of policies and actions endogenous to the system.
Sustainability Principles and Lessons	Sustainable dynamics involve interactions between (a) accumulations of human activity, (b) stocks of natural resources, and (c) investments intended to mitigate adverse impacts of human activity	Feedback among the three classes of stocks over time determine long term system behavior and often lead to unintended and undesirable outcomes.	Well-intended environmental policies may not be sustainable because they may trigger "better before worse" patterns of system behavior.
Sustainability Principles and Lessons for the Specific Domain of Coastal Protection	Coastal risk is driven by (a) long-term construction of structures near the coast that (b) degrade natural protective barriers such as wetlands, driving a need to invest in (c) protective barriers.	(see lessons in next panel)  	Attempts to protect the coast solely by investing in the built environment may be a self-defeating policy—(a) it sets off a self-reinforcing process of more development which (b) drives a need for more protective barriers and (c) further degrades naturally-occurring protective barriers

Research Plan

Our project has three aims: (1) Testing our hypothesis that we have captured the findings of the sustainability and resilience literature in our SBLE, simulation, and curriculum. (2) Testing our hypothesis that an SBLE is an effective mechanism for teaching these lessons in a way that is transferable and generic; and (3) Testing our hypothesis that the SBLE reflects the concerns and needs of the sustainability workforce of scientists, practitioners and stakeholders facing these issues. A successful proof-of-concept will facilitate the re-use of the SBLE approach for framing effective short- and long-term consequences for the hundreds of coastal communities facing uncertain outcomes and limited scientific data. Evaluation design plays a key role in answering these questions.

Figure 2 below sketches how our three research goals interact to create the project's products.

Figure 2: Major Products, Research Questions, and Evaluation Activities



The starting point for our work is the SBLE and simulation built upon decades of experience in the domain of coastal protection planning and management within the USACE. Our project will proceed through three linked activity streams tied to our three research aims. We envision iterative SBLE execution, evaluation, and improvement during the project as we refine our results.

Aim 1: Capture the systems lessons identified by the scientific literature

Task 1.1: Craft a First Draft of the Learning Objectives. Lessons to be operationalized within our SBLE will be assembled from four different sources: (1) decades of experience within the USACE, (2) learning objectives already incorporated into the existing *CoastalProtectSIM* model, (3) other lessons relating to socially constructed complexity from our literature review on decision making under complexity, and (4) best practices in coastal protection from the USACE and the selected workshop participants.

Task 1.2: Update the Initial Draft Curriculum Based on Project Outcomes. Our curriculum will be updated using three sets of evaluations as discussed in the Evaluation section below.

Task 1.3: Update the Statement of Lessons in the classroom and in the field. Based on the learning objectives and a formal evaluation of their effectiveness, we will update the lessons and integrate them into subsequent revisions.

Aim 2: Evaluate the SBLE for its effectiveness in teaching sustainability lessons in a way that is transferable and generic.

Task 2.1: Update the *CoastalProtectSIM* simulation. While we have been using our existing materials in our classrooms, we plan to integrate additional data capture for outcome evaluation and improve the model to render its policy and management lessons more clearly.

Task 2.2: Update and Create Related SBLE Learning Materials. Table 2 below suggests our overall design for evaluating both classroom-based and field-based versions of the SBLE. Wherever possible, we will use the established scripting-instructor teaming, as well as facilitation principles from the SDGMB literature to design these activities. [14],[33],

Task 2.3: Create an Evaluation Design for the SBLE in a controlled setting. The evaluation design discussed below provides the grist for the planned iterative updates.

Aim 3: Create an SBLE that reflects the concerns and needs of the sustainability workforce of scientists, practitioners and stakeholders.

The research team's work to date has focused on classroom activities, where we use systems concepts to train future government managers. In parallel, the USACE and the National Academies have noted the difficulty local governments face when evaluating real-world sustainability implementation options. We believe that our approach, if grounded properly in the needs of local communities, can assist in resolving this difficulty. To this end, the USACE has agreed to facilitate meetings with three coastal communities where we can test our SBLE and workshop model. The selection of these communities will be based on the community's strong working relationship with the Coastal Management Program at the USACE Institute for Water Resources (IWR).

Task 3.1: Embed the Core SBLE "Treatment" within a USACE Workshop. Using our classroom experience as a baseline, the SBLE will be implemented in the field portion of our work under USACE supervision.

Task 3.2: Design Field-Based Contextualization and Assessment Activities. To establish the value of our approach we will design appropriate assessments based on learning science. The SDGMB literature suggests a number of problem-defining and boundary-setting exercises that are appropriate for such groups to set context and map the experts' thoughts about causal impacts of policy options. The assessment of the field-based exercises also provides the opportunity to qualitatively assess the realism and relevance of the lessons embedded in the SBLE rather than trying to capture with controlled accuracy what lessons are actually being learned under what conditions.

Task 3.3: Design and Implement Field Based Workshops. This research will leverage ongoing relationships developed by the Corps to hold a series of workshops with local community coastal managers. Each workshop will include at least eight subject matter experts with a collective knowledge of all the coastal management decisions and stakeholder interests in their region, including economic development strategies (e.g., revitalization for local business and tourism); (2) natural environment protection; (3) structurally engineered mitigation protection; (4) zoning and emergency management policies; and (5) nonstructural mitigation solutions. Throughout, the assessment of these activities will use interview approaches and other qualitative assessment practices that are commonly used in evaluation research with dynamic simulation models[34], [35].

Task 3.4: Update and Refine the Overall Curriculum of Learning Objectives. The workshops feed into improvements in the overall curriculum discussed above.

Task 3.5: Ponder a More Generic Sustainability Curriculum of Learning Objectives. This project will develop and test our SBLE, teaching materials, and a simulation model that can then be shared with hundreds of other local communities to promote locally driven coastal protection in a sustainable manner. We will review our two years of experiment and field work, seeking insights into other climate sustainability and resilience domains.

Learning Science and SBLEs

While there are many examples of SD projects looking to evaluate the effect on their participants, we believe that this particular project has challenges for learning science. First, while our activities were developed for classroom use, the ultimate consumers are practitioners working with real problems. This does not lend itself to the typical control / intervention based experimental model. Second, we are unsure about the effects and effectiveness of collecting data during use of the model as well as during the workshop activities that surround the simulation. Third, can we create a convincing case that the lessons of the simulation are useful to decision-makers looking at coastal protection and other sustainability issues? Fourthly, will these findings be robust across the very broad set of environments that we believe might find value?

Evaluation of SBLE Effectiveness: Evaluation of the outcomes of our SBLE is a key component in answering questions in the three project areas. We propose the integration of Learning Science techniques in the evaluation of our SBLE. These tools will be applied to help us consider two broad research questions: What is the best way to evaluate the effect of the SBLE on participant learning? And how can the effectiveness of the SBLE be evaluated in a field-based workshop?

1. What is the best way to evaluate the effect of the SBLE on participant learning? Learning and creation of new knowledge about complex systems is one of the main goals of system dynamics [36], [37]. Additionally, evaluating and measuring learning is a critical component of effective system dynamics interventions. Evaluation of learning about complex dynamic systems is categorized in the literature into two forms: performance (the results of decision making/quality of the created model) and understanding (the rules/processes leading to decisions) [38].

Table 2. Major Components of Classroom and Field-Based Evaluations of SBLE with Controls for Classroom-Based activities

	Classroom Based		Field Based
Major Component	**SBLE**	**Control**	**SBLE**
Contextualization	-Read prepared Pointe Claire Case Materials -Background Reading on Coastal Protection	-Read prepared Pointe Claire Case Materials -Background Reading on Coastal Protection	-Problem Defining and other exercises drawn from GMB experiences and appropriate to selected group
Pre Test	-Structured survey materials focusing on policy levers, evaluation criteria and domain of coastal protection -Written essay on relevant selected topics	-Structured survey materials focusing on policy levers, evaluation criteria and domain of coastal protection -Written essay on relevant selected topics	-Qualitative assessment such as pre workshop interview to assess various topics identified as critical -Other relevant instruments (e.g., social network analysis)
Treatment	-Pre-simulation interaction with policy issues through written products -Structured interactions with simulator -Debriefing and written or "think aloud" products	- Strategic analysis exercises that are group centered with identical time on task characteristics	-Pre-simulation interaction with policy issues with written products -Structured interactions with simulator -Debriefing and written or "think aloud" products
Post Test	-Structured survey materials -Model-based experimentation with same or different context -Reasoning-based written final assignment	-Structured survey materials -Decide how to handle model-based evaluations? -Reasoning-based written final assignment	-Qualitative debriefing based on best practice from group model building scripts -Follow up with relevant instruments (e.g. social network analysis)
Evaluation	-Multiple measures possible, e.g. measure improvement from first to last run		-Use qualitative approach to assess realism and relevance of overall exercise
	-Measure the difference between the results of the final written assignments and results from the control group		

Bloom's Taxonomy of Educational Objectives [39] presents six categories of learning outcomes: remembering, understanding, applying, analyzing, evaluating, and creating [20]. This taxonomy has been applied previously in measuring outcomes of teaching system dynamics [40], [41]. Measuring at different levels provides the advantage of a more complete picture of participants' understanding. Therefore, we are employing several measures for evaluating products (level: apply), processes (levels: evaluate, create, analyze), as well as prior knowledge and knowledge gains during and at the end of the session, respectively (level: remember, understand).

In the classroom-based activities, we are aiming for investigating the effects of the SBLE on participant learning with an experimental design, where our treatment group interacts with the SBLE and the control group performs a group-centered strategic analysis exercise (Table 2). The open-ended and essay-type pre-tests will measure participants' prior knowledge on concepts outlined in the background readings. The qualitative analyses of written essays provide a measure of participants' mental models about the topic before interacting with the SBLE or the strategic analysis exercise [42],[43].

In the treatment phase in the experimental condition, pre-simulation written products including surveys and written essay responses will be collected and analyzed qualitatively [44]. While participants are interacting with the *CoastalProtectSIM* tool in groups, we will collect trace data in the form of voice recordings of all students' verbal interactions in groups as well as computer screen recordings of their actions with the SBLE. The analysis of verbal data (think-alouds) provides rich data on how participants go about articulating and testing their hypotheses; however, one of the limitations of this method is that it does not reveal the more general model behind the steps taken [45].

The time-stamped verbal discourse data will be transcribed and analyzed qualitatively for (a) hypotheses tried out by the groups, (b) reasons and explanations verbalized regarding the results of the computer simulation, (c) metacognitive verbalizations (e.g., reflection on and evaluation of products of discussions, discrepancies noticed between predictions and simulation results, monitoring progress towards goals set in the group or by the instructor/facilitator), and (d) evidences of change and refinement in their mental or causal models while interacting with the SBLE [43].

As part of a post-simulation exercise, a counterfactual thinking exercise [46] will be administered. This exercise makes use of "what-if" scenarios, and asks participants to think what could have been different if some variable from the event has been changed. The debriefing will serve as a reflection phase, where the facilitator will elicit metacognitive thoughts from the participants. All debriefing conversations will be recorded for further qualitative content analysis along the lines outlined above.

In the control condition, several types of facilitated, face-to-face, and synchronous activities will be deployed in order to scaffold and facilitate their understanding of the dynamic systems principles. In the post-test, survey material parallel to pre-test and reasoning-based exercises will be used to measure the participants' learning and perceptions in both conditions. These exercises will allow us to make reliable inferences regarding learning from pre- to post-test in participants and lead to revisions in the SBLE before implementation in the real-world workshop setting.

2. How can the effectiveness of the SBLE be evaluated in a field-based workshop?

In the field-based experiment, prior to the workshop, semi-structured interviews will be conducted to measure the prior knowledge of the participating experts on topics such as causal impacts of policy options [47]. Since the participating experts will be from different fields with differing interests and priorities, it is important to conduct the interviews to establish a baseline regarding the skills and knowledge of the participants in critical areas (e.g., dynamic systems, risk-benefit analysis). Furthermore, a coping appraisals questionnaire [48] will be administered to measure participants' perceptions of response efficacy (effectiveness of action in reducing threat), self-efficacy (beliefs that one can perform an action effectively), and response costs (perceived costs/risks associated with the taken action).

During the treatment phase of the workshop, several types of scaffolded exercises (e.g., graphs over time) will be conducted to measure participant experts' knowledge on topics such as causal relationships, tradeoffs, and risk perceptions regarding a current outstanding issue relevant to their community. Next, they will be asked to interact with the SBLE, attempt and test several of their hypotheses, and afterwards discuss their observations and findings with the workshop facilitator in a debriefing session (based on GMB scripts). This phase will be conducted similar to the treatment phase of the classroom-based study.

At the end of the workshop, interviews will be conducted with the experts to inquire into their experience with the SBLE and the workshop, what they had learned, their satisfaction (perception of consensus, communication quality, insight) and perceptions of change in their beliefs from before attending the workshop (self-efficacy measure re-administered: [34] [48]). Since these measures are self-reports, and individuals are not typically reliable reporters of their own cognitive processes [49], we will conduct qualitative and objective analyses on baseline, during (e.g., how much unique information was used in communication) [50], and post-test data to document changes in knowledge and system dynamics skills.

Epilogue

This project is a work-in-progress, and we anticipate advancing our ideas between now and the conference presentations with concrete examples and protocols for discussion. We look forward to the opportunity to review these with our colleagues.

Bibliography

[1] National Research Council (U.S.), *A National Strategy for Advancing Climate Modeling*. Washington, DC: The National Academies Press, 2012.

[2] M. Deegan, K. Stave, R. MacDonald, D. Andersen, M. Ku, and E. Rich, "Simulation-Based Learning Environments to Teach Complexity: The Missing Link in Teaching Sustainable Public Management," *Systems,* vol. 2, pp. 217-236, 2014.

[3] J. B. Atwater, V. R. Kannan, and A. A. Stephens, "Cultivating Systemic Thinking in the Next Generation of Business Leaders," *Academy of Management Learning & Education,* vol. 7, pp. 9-25, 2008.

[4] J. Sterman, "Interactive web-based simulations for strategy and sustainability: The MIT Sloan LearningEdge management flight simulators, Part I," *System Dynamics Review,* vol. 30, pp. 89-121, 2014.

[5] C. Ginger, "Integrating knowledge, interests and values through modelling in participatory processes: dimensions of legitimacy," *Journal of Environmental Planning and Management,* vol. 57, pp. 643-659, 2014.

[6] H. Botts, T. Jeffrey, W. Du, and L. Suhr, "2014 CoreLogic Storm Surge Report," CoreLogic, Irvine, CA2014.

[7] R. E. Morss, O. V. Wilhelmi, M. W. Downton, and E. Gruntfest, "Flood Risk, Uncertainty, and Scientific Information for Decision Making: Lessons from an Interdisciplinary Project," *Bulletin of the American Meteorological Society,* vol. 86, pp. 1593-1601, 2005/11/01 2005.

[8] T. Franck, "Coastal adaptation and economic tipping points," *Management of Environmental Quality: An International Journal,* vol. 20, pp. 434-450, 2009.

[9] Mississippi Coastal Improvements Program (MsCIP), "Hancock, Harrison, and Jackson Counties, Mississippi: Comprehensive Plan and Integrated Programmatic Environmental Impact Statement. Volume 1, Main Report," 2009.

[10] K. Cockerill, L. Daniel, L. Malczynski, and V. Tidwell, "A Fresh Look at a Policy Sciences Methodology: Collaborative Modeling for More Effective Policy," *Policy Sciences,* vol. 42, pp. 211-225, 2009.

[11] J. M. Bryson, "What to do when stakeholders matter: Stakeholder identification and analysis techniques," *Public Management Review,* vol. 1, p. 6, 2004.

[12] J. M. Bryson, G. L. Cunningham, and K. J. Lokkesmoe, "What to Do When Stakeholders Matter: The Case of Problem Formulation for the African American Men Project of Hennepin County, Minnesota," *Public Administration Review,* vol. 62, pp. 568-584., 2002.

[13] C. Eden and F. Ackermann, *Making strategy: The journey of strategic management*. Thousand Oaks, CA: Sage, 1998.

[14] D. F. Andersen and G. P. Richardson, "Scripts for group model building," *System Dynamics Review,* vol. 13, pp. 107-129, Summer 1997.

[15] E. A. J. A. Rouwette, J. A. M. Vennix, and T. van Mullekom, "Group model building effectiveness: a review of assessment studies," *System Dynamics Review,* vol. 18, pp. 4-45, 2002.

[16] K. A. Stave, "Using system dynamics to improve public participation in environmental decisions," *System Dynamics Review,* vol. 18, pp. 139-167, 2002.
[17] K. A. Stave, "Participatory System Dynamics Modeling for Sustainable Environmental Management: Observations from Four Cases," *Sustainability,* vol. 2, pp. 2762-2784, 2010.
[18] T. de Jong, J. Beishuizen, C. D.Hulshof, F. Prins, H. V. Rijn, M. V. Someren*, et al.*, "Determinants of Discovery Learning in a Complex Simulation," in *Cognition, Education, and Communication*, ed Mahwah, NJ: Erlbaum Associates, 2005.
[19] C. Blake and E. Scanlon, "Reconsidering simulations in science education at a distance: features of effective use," *Journal of Computer Assisted Learning,* vol. 23, pp. 491-502, 2007.
[20] J. P. Akpan, "Issues associated with inserting computer simulations into biology instruction: a review of the literature. ," *Electronic Journal of Science Education,* vol. 5, 2001.
[21] M. J. Jacobson and U. Wilensky, "Complex systems in education: scientific and educational importance and implications for learning sciences," *The Journal of Learning Sciences,* vol. 15, pp. 11-34, 2006.
[22] S. Järvelä and A. F. Hadwin, "New Frontiers: regulating learning in CSCL.," *Educational Psychologist,* vol. 48, pp. 25-39, 2013.
[23] K. Stave, H. Skaza, and B. Jurand, "Using Simulations for Discovery Learning about Environmental Accumulations," presented at the Proceedings of the 29th International Conference of the System Dynamics Society, Washington, D. C., 2011.
[24] K. A. Stave, "What can students learn from simple simulations about accumulations?," in *30th International Conference of the System Dynamics Society*, St. Gallen, Switzerland, 2012.
[25] H. Qudrat-Ullah, "Yes we can: Improving performance in dynamic tasks," *Decision Support Systems,* vol. 61, pp. 23-33, 5// 2014.
[26] L. P. Rieber, S. Tzeng, and K. Tribble., "Discovery learning, representation, and explanation within a computer-based simulation: finding the right mix," *Learning and Instruction,* vol. 14, pp. 307-323, 2004.
[27] J. Swaak, T. De Jong, and W. R. Van Joolingen, "The effects of discovery learning and expository instruction on the acquisition of definitional and intuitive knowledge," *Journal of Computer Assisted Learning,* vol. 20, pp. 225-234, 2004.
[28] T. de Jong and W. R. van Joolingen, "Scientific discovery learning with computer simulations of conceptual domains," *Review of Educational Research,* vol. 68, pp. 179-201, 1998.
[29] R. Mayer, "Should there be a three-strikes rule against pure discovery learning," *American Psychologist,* vol. 59, pp. 14-19, 2004.
[30] J. Zhang, Q. Chen, Y. Sun, and D. J. Reid, "Triple scheme of learning support design for scientific discovery learning based on computer simulation: experimental research," *Journal of Assisted Learning,* vol. 20, pp. 269-282, 2004.
[31] M. Ku, R. MacDonald, D. L. Andersen, D. F. Andersen, and M. Deegan, "Teaching and Learning about Complexity in Public Policy Decision Making:Using a Simulation-Based

Learning Environment in the MPA Classroom " *Journal of Public Affairs Education,* (forthcoming).
[32] G. P. Richardson, "Reflections on the foundations of system dynamics," *System Dynamics Review,* vol. 27, pp. 219-243, 2011.
[33] P. S. Hovmand, E. A. J. A. Rouwette, D. F. Andersen, G. P. Richardson, and A. Kraus. (2013). *Scriptapedia*.
[34] R. J. Scott, R. Y. Cavana, and D. Camerona, "Evaluating immediate and long-term impacts of qualitative group model building workshops on participants' mental models," *System Dynamics Review,* vol. 29, pp. 216-236, 2014.
[35] S. Huz, D. F. Andersen, G. P. Richardson, and R. Boothroyd, "A framework for evaluating systems thinking interventions: an experimental approach to mental health system change," *System Dynamics Review,* vol. 13, pp. 149–169, 1997.
[36] J. W. Forrester, *Industrial dynamics*. Cambridge, MA: MIT Press, 1961.
[37] J. D. Sterman, *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Boston: Irwin McGraw-Hill, 2000.
[38] M. Tabacaru, B. Kopainsky, A. Sawicka, K. Stave, and H. Skaza, "How can we assess whether our simulation models improve the system understanding for the ones interacting with them?," in *27th International Conference of the System Dynamics Society*, Albuquerque, New Mexico, 2009.
[39] D. R. Krathwohl, "Revising Bloom's Taxonomy: An Overview," *Theory into Practice,* vol. 41, pp. 212-264, 2002.
[40] K. Stave and M. Hopper, "What constitutes systems thinking? A proposed taxonomy," in *The 25th International Conference of the System Dynamics Society*, Boston, MA, 2007.
[41] M. Hopper and K. Stave, "Assessing the Effectiveness of Systems Thinking Interventions in the Classroom," presented at the Proceedings of the 2008 International Conference of the System Dynamics Society, Athens, Greece, 2008.
[42] N. M. Seel, "Model-centered learning and instruction," *Technology, Instruction, Cognition, and Learning,* vol. 1, pp. 59-85, 2003.
[43] H. Kim and D. F. Andersen, "Building confidence in causal maps generated from purposive text data: mapping transcripts of the Federal Reserve," *System Dynamics Review,* vol. 28, pp. 311-328, 2012.
[44] J. M. Corbin and A. L. Strauss, *Basics of qualitative research: techniques and procedures for developing grounded theory* Thousand Oaks, CA: Sage, 2008.
[45] G. P. Goodwin and P. N. Johnson-Laird, "Reasoning about the relations between relations," *Quarterly Journal of Experimental Psychology,* vol. 59, pp. 1047-1069, 2006.
[46] K. Epstude and N. J. Roese, "The functional theory of counterfactual thinking," *Personality and Social Psychology Review,* vol. 12, pp. 168-192, 2008.
[47] B. Kopainsky and L. F. Luna-Reyes, "Closing the loop: promoting synergies with other theory building approaches to improve system dynamics practice," *Systems Research and Behavioral Science,* vol. 25, pp. 471-486, 2008.
[48] T. Terpstra and M. K. Lindell, "Citizens' Perceptions of Flood Hazard Adjustments: An Application of the Protective Action Decision Model," *Environment & Behavior,* vol. 45, pp. 993-1018, 2013.

[49] J. K. Doyle, "The cognitive psychology of systems thinking," *Systems Dynamics Review,* vol. 13, pp. 263-265, 1997.

[50] M. H. McCardle-Keurentjes, E. A. J. A. Rouwette, and J. A. M. Vennix, "Effectiveness of group model building in discovering hidden profiles in strategic decision-making," in *26th International System Dynamics Conference*, Athens, 2008.