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# Teaching across disciplines: a case study of a project-based short course to teach holistic coastal adaptation design

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## Abstract

Climate change has led to the need for innovation in resilient infrastructure and the social policies which will support those. This requires greater interdisciplinary interactions and knowledge building among emerging professionals. This paper presents a case study of a pilot short course intended to immerse graduate students in the design of resilient infrastructure using place-based and interdisciplinary active team learning. This course helps graduate students bridge the gap between research and practice on the social science and engineering of resilient infrastructure for coastal adaptation. The intellectual framework for the course (the Adaptive Gradients Framework) provides a holistic evaluation of adaptation design proposals and was used to recognize the complexity of social, ecological and engineering aspects and varied social benefits. The course provides a model to move outside rigid boundaries of institutions and disciplines to begin to build, in both students and instructors, the ability to work more effectively on complex social-ecological-engineering problems. Finally, this paper presents a summary of lessons learned from this pilot short course.

## Introduction

There is widespread agreement across multiple sectors that the increasing severity of climate hazards requires a new approach to developing and managing coastal infrastructure (e.g. Bridges et al. 2015). Recent years have seen significant innovation in options for coastal restoration and protection (Sandifer et al. 2015; Sutton-Grier et al. 2015), and projects now include approaches that go beyond traditional infrastructure to include green or nature-based practices as well as social and regulatory approaches. One of the challenges of this broader portfolio of approaches is that it requires consideration of biophysical, engineering, economic, legal and socio-cultural components, each with their own discipline-specific practices and terminology, posing logistical and methodological challenges. This suggests the need for holistic evaluation

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of projects as well as interdisciplinary education to prepare today's students for that approach. One way to conceptualize the challenges and potential of this sort of work is through convergence, defined by the National Academies of Sciences, Engineering, and Medicine (NAS) as an approach to problem solving that crosses disciplinary boundaries, integrating "knowledge, tools and ways of thinking" from a wide range of disciplines to "form a comprehensive synthetic framework for tackling scientific and societal challenges that exist at the interfaces of multiple fields" (NAS 2014). Much of the literature around convergence has been towards facilitating research; here we focus on graduate-level pedagogy that can support students in building skills to work in transdisciplinary arenas such as coastal resilience.

There is a multitude of scholarly articles, courses, workshops, conference sessions and trainings that provide a rich landscape to learn about coastal impacts and adaptation. There are also many well-conceived and effective one- or two-semester university capstone-type courses that integrate student learning in this domain. However, the teaching, learning, design and assessment of these projects is often discipline-biased and may lack a fully integrated, multi-faceted approach that can enable transdisciplinary convergence practice.

This paper presents a case study of a pilot short course developed to address this educational need. The five-day course was designed for an international mix of graduate students from the U.S. and Caribbean. The short duration was intentional: as noted above, while traditional courses exist to convey some of these integrative principles, we wanted to test a model for the delivery of this approach in a compressed time schedule. The core pedagogical principles of the course were to use place-based, interdisciplinary and active team learning to create an experience for students' future disciplinary studies and professional lives. We used a holistic project evaluation approach called the Adaptive Gradients Framework to integrate discussions across disciplines as well as to investigate synergies in design solutions. The course was intended to help graduate students bridge the gap between research and practice regarding the design of resilient infrastructure for coastal adaptation. A summary of the short-course objectives and format are presented, as are results of a course evaluation survey, and a summary of lessons learned on the initial course delivery (which reflects student feedback) to help improve future course offerings. While this course focused on coastal resilience issues, it is easily envisioned that the same approach could be used to teach students holistic design for inland areas, many of which face increasing river-based flooding, periodic drought, and heat wave health challenges (IPCC 2014), or in fact for other topics in which convergence across multiple disciplines is the way of the future.

## Background

The US National Science Foundation (NSF 2020) identifies convergence research as having two primary characteristics:

- "Research driven by a specific and compelling problem. Convergence research is generally inspired by the need to address a specific challenge or opportunity, whether it arises from deep scientific questions or pressing societal needs.
- Deep integration across disciplines. As experts from different disciplines pursue common research challenges, their knowledge, theories, methods, data, research communities and languages become increasingly intermingled or integrated. New frameworks, paradigms or even disciplines can form sustained interactions across multiple communities."

Convergence is considered the next step on the continuum of collaboration, where "multi-disciplinarity" involves sequential work with researchers checking in with collaborators in other disciplines; "interdisciplinarity" involves joint exploration of knowledge based on individual's discipline-specific knowledge and "transdisciplinarity" means developing shared conceptual frameworks to create new models (Stokols 2018). While convergence began as an approach to integrate nanotechology, biotechnology, information technology and cognitive science (Roco and Bainbridge 2002), it is increasingly seen as essential for engineering (NAS 2017), biomedical (Sharp 2011; Wilson 2019) and geoscientific (McNutt 2017) fields. The Adaptive Gradients Framework facilitates convergence research by bringing together engineering, planning, social science, ecology and landscape architecture, and suggests a stronger integration of social science and design practices along with the more commonly discussed engineering and physical sciences.

Convergence-based research requires students who are well grounded in their specific discipline and also trained to work collaboratively across disciplines with enough knowledge of the wide range of relevant specialities to communicate effectively (NAS 2014). Students will need to know both what they know and what others might know better than them. As described by Colgoni and Eyles (2010), pedagogies need to be developed that will train a student who "understands a broad range of disciplinary approaches, is able to ask creative questions, and is trained to answer those questions with diverse tools. This 21st-century scientist must have a skill set that allows him or her to probe and explore problems, to find and critically evaluate information, to work productively as a member of a team, and to effectively communicate research findings to others".

In determining how to design a course that could achieve these goals, we turned to literature on integrated teamwork

and knowledge transfer, which are essential to the advancement of sustainability principles and the consideration of both social and natural science elements within the topic of sustainability (Clark et al. 2017; Kajikawa et al. 2014; Killion et al. 2018; Moore 2005). In considering effective methods of teaching and learning regarding environmental education, place-based learning (with somewhat different emphases also known as community-based learning, service-learning, environment as an integrating concept [EIC] and contextual learning) is one of the most accepted forms of integrated and engaged learning (Powers 2004). Place-based learning bridges between the contextual community and academic theory is supported by real-world problems relevant to the learner's community and acknowledges a variety of stakeholders. Research suggests that this perspective and connection to the project increase intrinsic motivation and improves a learned outcome (Howley et al. 2011; Powers 2004; Verba and Tinker Perrault 2017). Place-based learning is a particularly useful educational practice in helping link technical concepts to societal issues and other disciplines (Gosselin et al. 2016).

There is a need to close the gap between the scientific and the non-scientific environmental considerations in sustainability research. This is best accomplished through team-integrated learning (Christie 2011). Specifically, team-based learning, in which teams are composed of members from different disciplines or with differing individual skill or knowledge sets, promotes collaboration in problem solving and expanded perspective in considering a problem or challenge (Killion et al. 2018; Masters et al. 2013). The most important elements of effective team-based learning experience include group formation and management, member accountability, feedback and an assignment that promotes learning and team development (Michaelsen and Sweet 2008). This type of learning is driven by participants from varied disciplines in an environment where existing assumptions are challenged and new perspectives, questions and solutions are considered (Moore 2005).

Team-based learning can be further bolstered by a case-based learning. As introduced by Verba and Tinker Perrault (2017), case-based learning introduces problems in which learners must pursue the development of creative solutions, independent of a detailed process to achieve an ideal solution; learners must understand stakeholders and develop user-centred solutions.

A key approach to multidisciplinary team building is having a centering device that enables shared conversation, and the course utilized the Adaptive Gradients Framework for this. The Adaptive Gradients Framework was developed under a National Science Foundation Research Coordination Network grant (ICER-1338767) known as the SAGE (Sustainable Adaptive Gradients in the coast Environment) project. The short course described in this article is also a product of the NSF grant. The Framework (Hamin et al. 2018) was

developed as a qualitative, flexible and collaborative method for organizations to understand, evaluate and select diverse kinds of coastal adaptation responses. Adaptation measures that are developed using this framework reflect an inclusive set of inputs, leverage a broad range of solutions and measure efficacy and success using a comprehensive set of metrics. The framework is an evaluative and decision-support tool intended to lead to more sustainable adaptation solutions than those derived from a more restricted set of disciplines.

The Adaptive Gradients Framework (AGF) enables systematic review of project designs based on eight metrics or "gradients"—scaled characteristics representing a broad range of possible benefits from resilient infrastructure projects: Exposure Reduction, Cost Efficiency, Institutional Capacity, Ecological Enhancement, Adaptation over Time, Greenhouse Gas Reduction, Participatory Process and Social Benefits. The AGF "grade" or result for a given project is comprised of a set of ratings on a slider scale, one for each gradient, each of which is accompanied by a rationale. A higher gradient rating means that the project achieves the gradient goal to a higher degree. For an agency or other multiple project managers, the approach could be used to evaluate an overall portfolio. The use of the gradient analysis is meant to be a formative process that ensures that the most important interdisciplinary aspects of a proposed or existing project are discussed, analysed and evaluated. Further, the AGF provides a platform to encourage interdisciplinary learning; the gradients are a pedagogic tool to encourage holistic thinking and expand interdisciplinary education in resilient infrastructure.

## The SAGE short course: case study description

As part of the educational pathway mission of the SAGE grant, planning was initiated to offer a learning experience designed to share the AGF, provide just-in-time supplemental background information and practical skills to supplement attendees' educational/disciplinary training and provide this in a relatively short-duration experience. Individuals would then work together in interdisciplinary teams to design and present their adaption designs at week's end. The AGF would be used as a means for students from different backgrounds to come together and work towards a common goal. Early in the course design process, it was determined that the short course's impact could be most effective by offering the course to graduate student attendees who will become future researchers, practitioners and policy-makers. The ultimate goal of the week-long course was for each team to develop a resilience-improving hybrid structural/social/ecological infrastructure design for a particular site. The course agenda was organized around the eight AGF gradients, in both lecture and active learning through practice. Additional information regarding development and application of the AGF is provided

in Fricke and Hamin Infield (2019). Table 1 provides a summary of the course elements (lectures and activities) mapped to the respective AGF gradients.

The week-long summer short-course format was specifically selected as it provided flexibility of scheduling, logistics and enrolment. The course was funded in part by the SAGE grant. Boston was chosen as the location for several reasons: ease of travel to and from attendees' home locations, availability of resources at Northeastern University to host the course and access to coastal case study sites. The team also benefited from a combination of funding sources such that all attendee travel and accommodations during the course were fully paid. An initial call for applications resulted in a highly diverse and competitive applicant pool. Of the 54 applications received, a final group of 27 was selected and ultimately attended, including two students from the University of the West Indies, and one student from Puerto Rico attending a U.S. institution. Of those 27, three were advisees of faculty involved in the SAGE network; because their prior knowledge of the AGF, these students were assigned to separate design teams, where they served as facilitators and resources for their respective team members. Students were specifically chosen to represent diverse disciplines, ranging from engineering to

social science to ecological sciences, which aligned well with the Adaptive Gradient framework approach to coastal adaptation.

In order to form teams with multiple disciplines and skill sets required to complete the project, a pre-course questionnaire was sent out to selected students to assess their familiarity with Excel, MATLAB, AutoCAD, Google Earth, Google SketchUp, ArcGIS, Word and PowerPoint. Using all of these student attributes (discipline, degree level, skills), design teams were formulated by the organizers. Specially, each team consisted of four or five graduate students, and included a mixture of master's and doctoral level students. Further, each team had at least one representative from each of the three major disciplines: social, technical and ecological.

The course agenda was designed to include elements in four major focus areas:

(1) Drivers that lead to the need for a coastal adaptation solution: waves, climate, sea-level rise, socio-economic factors and ecological/biological issues.
(2) Tools that either directly measure necessary design parameters or obtain input from other sources (e.g. geology

**Table 1** Summary of course elements mapped to AGF gradients

| Gradients | Short course agenda item |
|---|---|
| All (general) | • Introduction to SAGE (definitions of the "gradients") |
| | • SAGE case study (students were provided a site description for a project in Puerto Rico. They were asked to score each of the eight gradients according to the AGF and discuss how the project might be improved. SAGE practitioners were available to provide input for this pre-established AGF case study.) |
| | • Presentation of sites and associated data (nature of the problem, goals/objectives of the client) |
| | • Group work (breakout time, workshopping designs) |
| | • Final presentations |
| 1. Exposure reduction | • Basic data needs for project design (tides, storm tides, and sea-level rise, wave conditions, beach characteristics) |
| | • Site conditions (site measurements, observations, surveying basics, Google Earth for rough design dimensions, MA state database of Lidar data) |
| | • Student exercise with range finders (outdoors) |
| 2. Cost-efficiency | • Modelling coastal scenarios and solutions |
| 3. Institutional capacity | • Definitions and examples of grey/green, structural non-structural |
| 4. Ecological enhancement | • Caribbean perspectives |
| | • Zoning, permitting, environmental considerations |
| | • Nahant ecology and greenhouse tours |
| 5. Adaptation over time | • The nature conservancy on living shorelines |
| 6. Greenhouse gas reduction | • Flooding: climate change adaption/scenario planning |
| | • Nahant ecology and greenhouse tours |
| 7. Participatory process | • The nature conservancy on living shorelines |
| | • Participatory process, mass state framework |
| | • Caribbean perspectives |
| | • Site visit (interviewing members of the public visiting the site) |
| 8. Social benefits | • Demonstration of mentalmodeler.org software (related to case study) |
| | • Site visit (interviewing members of the public visiting the site) |

maps, satellite imagery, field measurements, stakeholder interviewing, census data, scenario modelling, mental mapping).

(3)  Solutions that are considered as part of the design: green versus grey infrastructure, policy solutions, community input and impacts and economic issues that may drive the solution.

(4)  Evaluation of potential solution sets based on the Framework to ensure that students considered the broad range of possible goals their proposals could achieve.

These focus areas were covered as background at the beginning of the week. As Pennington (2016) notes, interdisciplinary teams can be challenged by the need to quickly integrate knowledge from other disciplines. For the AGF Short Course, background information was designed to supplement students' training across disciplines, such that social science students would gain more of an engineering perspective and engineers would learn some social and behavioural research practices. This background information was delivered using multiple modalities: instructional lectures, active learning through practice (for example, learning to use range finders, an easy-to-learn instrument for distance and elevation measurements), guest speakers and a tour of Northeastern University's Marine Science Center (MSC) that provided the chance to hear about bio-ecological drivers in coastal projects. In this manner, the students developed experience with the skills and language related to the AGF analysis to use during their design development and proposal.

Students then chose one of two study sites for their design focus:

•  George Lane Beach in Weymouth MA: has a history of flooding and storm water management issues. It is apparent that the existing seawall is insufficient to protect the beach, a road providing the only connection between the neighbourhood and the mainland, and surrounding houses. The purpose of this project was to develop a plan for reducing flood risk, while enhancing social and ecological benefits to the site and, ideally, providing a view that is more aesthetically pleasing than a traditional concrete wall.

•  Squantum Point Park is a former Navy air station located in Quincy, Massachusetts. Despite its current use by local residents for recreation, it faces several immediate challenges including the presence of a large dilapidated seawall, lack of facilities (e.g. bathrooms, water fountains) and general underuse as a recreation resource. Additionally, the park is prone to flooding during storms. The park is in need of creative, adaptable and sustainable planning.

Time was allotted for the groups to be onsite to gain a sense of the physical space, make simple measurements with the range finders and undertake structured as well as informal interactions with stakeholders and visitors at each of the sites. Students began developing their design solutions, with course mentors circulating among the groups to answer questions and provide feedback. The following days interspersed time allotted to teamwork with brief lectures on relevant topics.

The course concluded with a final design presentation by each team modelled after the practice Puerto Rico case study that the students worked through earlier in the week. Students gave an overview of the physical and social aspects of the sites, presented results of their field data collection, showed design concepts and then focused on a "preferred design". As a requirement of the final presentation, each team needed to rate their project according to the AGF framework.

An example of one of the proposed solutions to the George Lane Beach Site, and its corresponding score of the AGF framework, are provided as Figs. 1 and 2, respectively.

As Christie (2011) indicates, currently, natural sciences dominate the construction of environmental problems and there is little integration of natural and social science. Further, the predominant environmental policy process has assumed, implicitly or explicitly, that the key knowledge gap to effective policy-making is inadequate knowledge of ecological function. Therefore, a proposed design which weighted social science and ecological gradients nearly equally to that of natural science gradients was considered a "successful" design, and likewise, all disciplines within the team were represented.

## Findings from course evaluations by attendees

In order to assess the efficacy of the short-course learning model, course attendees completed an online assessment survey at week's end. The organizers were especially interested in how well the class structure of interdisciplinary teams, focusing on place-based projects and using the AGF, was able to meet the course goals of interdisciplinary learning and problem solving.

The survey included detailed questions about the 14 content sessions (lectures, applications and field trips). Both quantitative and qualitative data were collected. The quantitative data was generated in response to the prompt: "Please rate your experience" on a 1–5 scale with 1 = poor, 2 = fair, 3 = good, 4 = very good and 5 = excellent (see Fig. 3). Qualitative data consisted of comments written about each of the 5 days of the short course and was coded using an inductive approach to identify key themes.

Of the 27 attendees, 22 responded ($N = 22$), and the response to the course was highly positive; the average of all

**Fig. 1** Team-based student proposed design concept for George Lane Beach site. One team's proposed design concept solution to the George Lane Beach Site. The concept included elevating the road with vegetation planted on the residential side. The elevated road forms an embankment to minimize flooding while the vegetation makes the site more aesthetically pleasing, and resulted in a lower carbon footprint (relative to a traditional concrete wall). This design concept was presented by one of the five teams during the final presentations to the SAGE members and the remaining four student teams
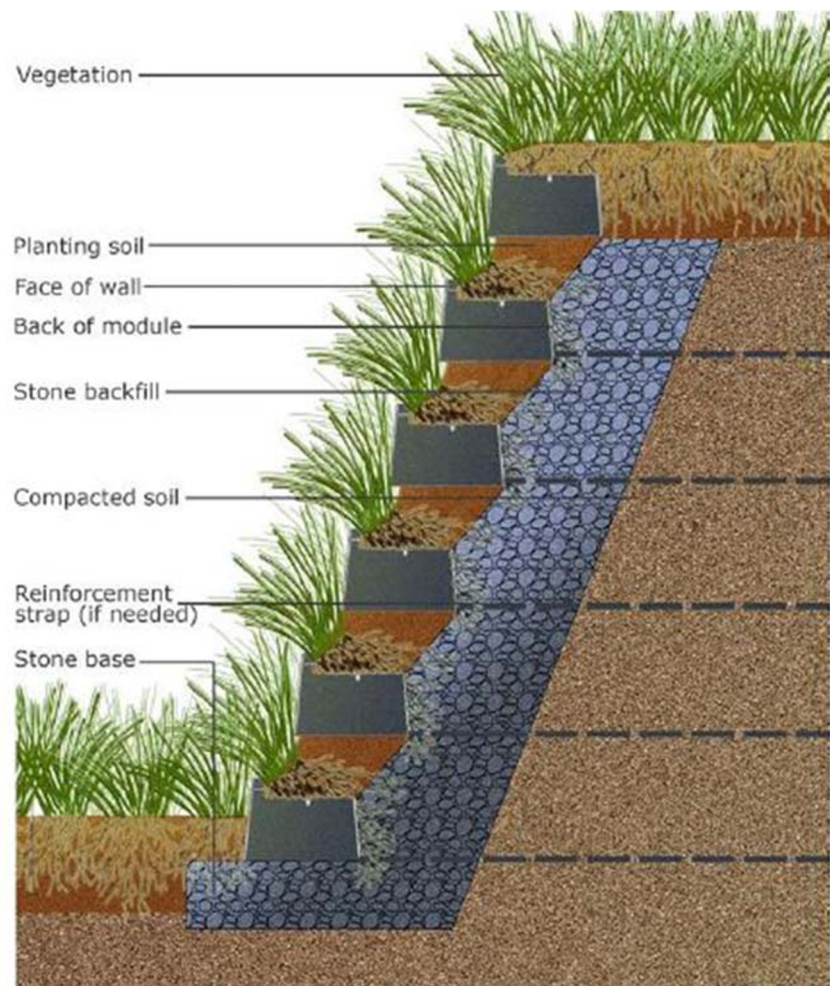


the evaluation scores was 4.35, which corresponds to "very good" to "excellent". Participants appreciated learning about coastal adaptation science and planning from different disciplines and perspectives; group work in which they were able to apply lecture material and form social connections and learning from teammates from different disciplines. Several students noted they had never considered issues outside of their respective disciplines in their previous work.

Considering the mean ratings for the individual content sessions, the highest mean rating (4.76) was received by a session which highlighted the role of the institutional capacity gradient. In this session, two course attendees (graduate students from the University of the West Indies) presented sample Caribbean region projects which they were involved in implementing. The knowledge base of both presenters was also notable; both had prior work experience as practitioners outside of academia. The high ratings reflect the importance of the international and cross-cultural component of this session, as well as the value of peer-to-peer knowledge and experience sharing.

The next highest mean rating (4.68) was associated with the study site visits where students heard some of the history,

politics and perceptions of proposed adaptation measures from stakeholders. To support AGF gradients of Participatory Process and Social Benefits, the site visits included opportunities for the students to engage with local residents. It is noteworthy that students with technical backgrounds assumed that their proposed design work would be overwhelmingly welcomed by local residents. They instead encountered strong feelings for and against any ideas of change at the two sites, making the site visits especially impactful to those students. The field trip to the Northeastern University MSC in Nahant was also regarded favourably as a welcome change of pace with interesting content related to the Ecological Enhancement and Greenhouse Gas Reduction gradients.

A lecture on zoning and permitting, relating to the legal aspects of the Ecological Enhancement gradient, had the lowest rating of the sessions (3.91), perhaps because this was presented at the end of the first day of lectures and did not have an interactive element.

In the evaluation comments, participants identified some challenges in the short course and had suggestions for improvement. In addition to expected comments about some
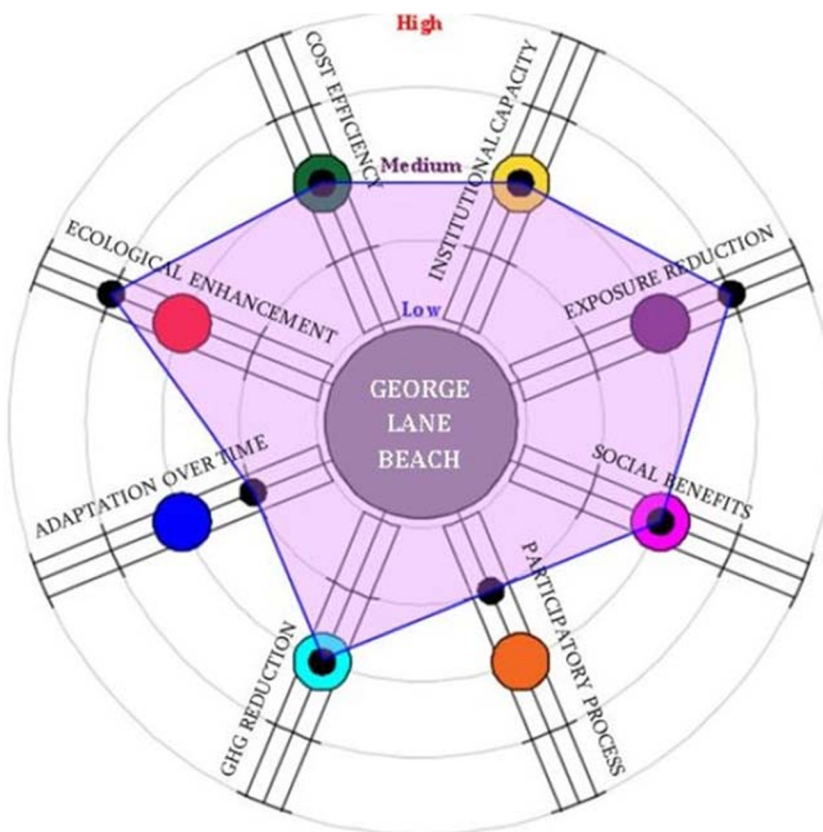
**Fig. 2** Evaluation of proposed George Lane Beach design in accordance with AGF Framework. The results of the AGF framework for the proposed design concept (presented in Fig. 1). The fit of the design concepts with respect to each of the eight gradients was scored by the team members on a basis of 1–5, with 1 being low (less resilient) and 5 being high (more resilient). The small black dots represented the average value of the group members' individual scores. Those average values were then plotted with respect to a sliding scale, with the larger coloured dots

representing a value of 3 (moderately resilient). Black dots shown outside of coloured dots are gradients in which the proposed design was deemed particularly resilient (exposure reduction and ecological enhancement). Gradients where the black dots were closer to the centre of the diagram (compared to the coloured dots) represented gradient with potential room for improvement in terms of resilience (adaptation over time and participatory process)

groups working more harmoniously than others, there were multiple comments on the tendency of group members to

work mostly "within their comfort zone to meet [the] tight deadline", and a student suggested that perhaps:
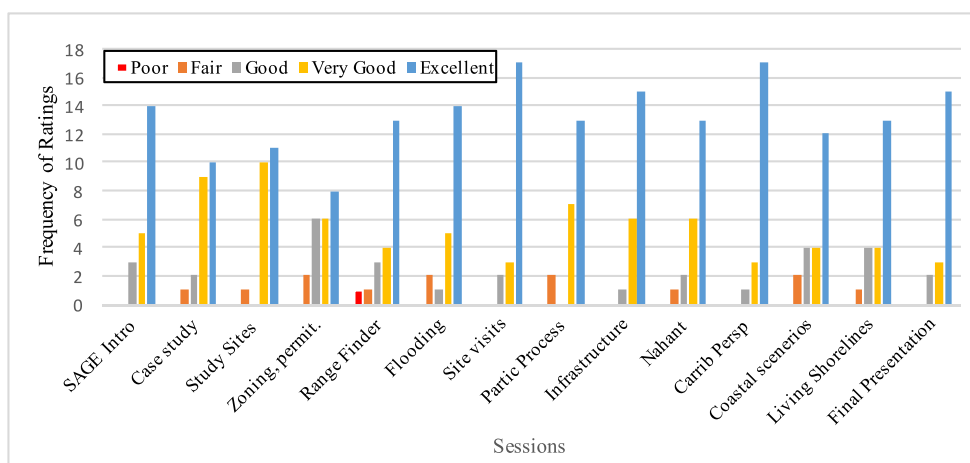


**Fig. 3** SAGE short course participant evaluations. Results of the course evaluation survey in which students assess their experience in each of the sessions that occurred over the week-long short course. Twenty-two individuals (out of a total of 27 participants) responded to the survey. The highest mean rating (4.76) was received by the Caribbean Perspective

session, which highlighted the role of the institutional capacity gradient. The Zoning and Permitting session (which related the legal aspects of the ecological enhancement gradient) had the lowest rating of the sessions (3.91). The relevance of each session, and its corresponding AGF gradient, is summarized in Table 1

… a series of short design challenges/class exercises could complement the daily lectures. This could expose participants to a wider range of problems; encourage more working outside one's discipline; enliven the lecture format; and provide opportunities for different work partners.

The course had high ambitions with just 1 week to achieve them. A longer time might have allowed more extensive team-building exercises to support general interactions among team members and improved overall team dynamics. Pre-work, conference calls and/or virtual meetings among team members prior to starting the course could have supported this objective, and reduced the intensity of the information "preloading" that occurred in days 1 and 2. Students also wanted a more extensive debrief session after the final presentations, and a planned group activity at the end, indicating a desire for a formal sense of closure at the end of the course. That being said, the final presentation session earned a strong score of 4.65 indicating that the course goal (interdisciplinary learning and problem solving with a focus on place-based projects using the AGF) was met by the end of course.

Students seemed to find having an evaluation rubric such as the AGF helpful; attendees wanted more initial coverage of the Framework, which was limited to a relatively short, day 1 presentation. And while the course sought to cover all important disciplinary areas related to the AGF, some participants felt that contributions from social science, including participatory planning, were given less time and emphasis as compared to engineering and natural science. A student wrote:

> Both the presentations on adaptation and participatory process covered the topics very cursorily. While I understand that we didn't have much time, this may be some people's first exposure to these topics …. I thought it could leave people with too simple of an idea of these complex and important topics.

This likely reflected the fact that the course was organized by two engineers who delivered a considerable amount of the overall course teaching, with more limited participation by social scientists. There was also a sense during the course planning that for the students to complete their designs by week's end, an emphasis had to be placed on technical aspects versus non-technical factors. This also likely reflected the considerable amount of time dedicated upfront to building initial information and skills to allow the students to approach a coastal adaptation problem. In the future, to save time, perhaps the early building lessons could be more "impromptu" or "pop up" style to meet the specific needs of the individual students. For example, students could have access to a shared board where they write down questions as they arise. Once several questions are listed that focus on a common theme, the instructor most familiar with the area of study (social, technical or ecological) could provide a pop-up short lecture to respond to those specific questions.

It is important to note that, while the societal component of the short course was generally perceived as lacking, a few students in the technical disciplines noted that they were impressed by the societal elements introduced. One student wrote:

> Coming from a physical sciences background, what I found most fascinating were the social and ecological themes that were covered.

This is an important observation and supports the value of the AGF approach, as technical students (especially engineers) often do not learn about societal impacts of their projects in their traditional curricula. They may also see societally based gradients (e.g. Institutional Capacity, Participatory Process, and Social Benefits) as subjective given their disciplines' reliance on objective data collection and interpretation. In this manner, this short course was highly valuable in opening the eyes of technical students to social issues which they may encounter in practice, and likewise, acted as a bridge between academia and practice as the technical students approach their graduation.

Another valuable student comment was that content was taught from the individual discipline silos, suggesting that even within the interdisciplinary focus of the AGF framework, overcoming habits is difficult:

> Course was not interdisciplinary, it was multidisciplinary. Each subject was talked about in its silo (besides the Caribbean perspectives) rather than bridging those silos. Bridging the silos was put on us to do in our teams and that was hard.

Both students and instructors thought that having more opportunities for discussion across disciplines, especially modelled by the instructors, would help participants learn how to broach disciplinary boundaries. This clearly demonstrates the need for keen self-reflection as instructors undertake course design, assuring that we do not reproduce the very behaviours and beliefs that the course was designed to overcome.

When students were asked about the most important takeaways from the course, four categories of responses resulted: technical knowledge, perspective, application and networking. Under the technical knowledge category were items such as learning a skill (conducting a physical site study, using the rangefinder, learning Google SketchUp software); learning about living shoreline options, and infrastructure options;

and becoming more aware of societal aspects of design projects. The perspective category included learning about a holistic approach to planning for sustainability and viewing coastal adaptation through the lens of different disciplines. Application refers to using available data sources in collaboration with group members, and applying knowledge to form design solutions for real-world problems. One participant noted that this process "helped me realize gaps in my own knowledge" and another noted they had learned "the importance of establishing communication between experts and community for more sustainable infrastructure". Finally, the networking category included connecting with fellow students and instructors; spending time with people from different regions and across disciplines and hoping for ongoing connections with students and faculty.

## Lessons learned

As with any initial instructional offering, several lessons were learned from the pilot short course based on organizing the group reflection and student course evaluations. We focus on those areas involving interdisciplinarity and teamwork in the overall programme.

**Instructor teamwork is the first step in interdisciplinarity** Curriculum design needs to be done with full representation from all relevant disciplines, and should include enough time for the instructors to meet and talk in an iterative fashion, gaining at least the level of common language and understanding as we hope students will achieve. In other words, the team of instructors must model interdisciplinarity early and often. Students could observe the instructors from technical, social and science disciplines working through an AGF case study for a different site (e.g. Puerto Rico). The students could then learn from the modelling of the instructors and apply that model to their respective new site.

**Student pre-work can play an important role** Time is extremely limited with a 1-week course, and the desire to educate students can easily push out team-building activity. Future course offerings could address this by either putting disciplinary fact-based education as up front, prior to the in-person workshop, or by incorporating team-based activities that the students need to complete prior to arrival at the course, including virtual meetings, coverage of introductory level topics and gaining an understanding of discipline-based technical definitions and terms of art. The organizers later reflected on the fact that the AGF was developed by an interdisciplinary panel of academics and practitioners over several years and multiple iterations to develop, in large part because of the substantial amount time required to develop a common language among the various members. Short-course teams needed the

opportunity to arrive at that same common understanding, if only at a rudimentary level.

**Having a project evaluation tool that required consideration across multiple criteria helped broaden student designs** The student teams were required to explain how their design supported each of the eight gradients during the final presentation. Further, the designs were critiqued by SAGE members and fellow students. In this manner, the AGF ensured that teams had to consider a wide range of project goals and that students would talk about a range of aspects of their designs (Fig. 2).

**Time pressure tends to privilege technical learning; balance will require strong efforts at integrating social issues into learning outcomes** A general cultural bias privileging "physical" science, combined with a desire by both instructors and student team members to get the designs "right", encouraged the prioritization of technical knowledge over social sciences. For example, students, particularly when facing a time constraint to complete their deliverable presentation, tended to focus on the easily quantifiable gradients (e.g. Exposure Reduction and Cost Efficiency), at the expense of considering less quantifiable social gradients; significant social science input is critical. Achieving a more even balance would require what might seem like outsized attention to social sciences in the curriculum as well as the design proposals themselves. Students must engage in periodic check-ins with a professor of the social science disciplines throughout the week to ensure those objectives of the AGF are adequately achieved.

**Allow time for instructor-led interdisciplinary activities** Meaningfully integrating interdisciplinary elements during design development was often left to the teams to tackle themselves. While students certainly learned through this challenging process, it is important to make sure the thrust of the class remains "interdisciplinary" and not simply "multidisciplinary".

**Conduct a facilitated, end-of-course debrief session** The short course ended with the team presentations of their final proposal to the other teams and a panel of SAGE members. A brief set of concluding comments was presented by instructors and course organizers, and then students departed. Additional time should be provided following the presentations to allow students to discuss the alternative proposals, and tie in the presentations to the broader themes of the week, and closing networking opportunities.

## Conclusion

The complexity of global problems such as climate change will require convergence approaches that focus multidisciplinary teams on specific projects, use of shared

frameworks and innovative approaches. However, this requires new approaches to developing solution alternatives, and effectively integrating the multitude of required disciplines needed to arrive at those alternatives. The development of the AGF provided the formalized research structure to address coastal adaptation in the face of climate change. From this work, it became clear that an educational pathway was needed to shape the next generation of practitioners in this area, and the SAGE AGF short-course pilot was conceived. This course was developed to take place outside of the normal educational framework, enabling efficient delivery and enhanced innovation using team- and place-based learning around a project design proposal. The pedagogy used the AGF as a quick way to centre discussions across disciplines, and built active learning through place-based and team-based pedagogy. These factors allowed a means for students of different backgrounds to work together towards a common project goal, as defined by the course organizers.

The findings from the pilot SAGE short course confirm the importance of enabling collaborative learning, integrating technical and non-technical knowledge, application to real-world issues, and active learning for the development of improved resilient infrastructure and coastal adaption design. Practical skills and knowledge were introduced in experiential learning, which provided opportunities for holistic integration of thinking, perceiving, taking action and communication. Overall, the response to the course was highly positive. Participants appreciated learning about coastal adaptation science and planning from different disciplines and perspectives; and mostly appreciated the group work in which they were able to apply lecture material, learn from teammates from different disciplines and form connections with group mates.

Reflecting upon the course design, the instructors believe that the use of AGF was essential in creating a pedagogy that would enable convergence practice. It offers a platform for engineers and natural scientists to learn about social gradients (such as Participatory Process and Social Benefits) and, simultaneously, offers social sciences a deeper understanding and appreciation for the work traditionally performed by engineers and natural scientists (such as Exposure Reduction and Cost Efficiency). The SAGE short course helped graduate students by bridging the gap between research and practice regarding the design of resilient infrastructure for coastal adaption. Moving forward, universities can use the AGF and week-long short-course format to test a proof-of-concept. In this manner, universities can determine if their programme(s) may benefit from a change to the curriculum which supports educational opportunities for interdisciplinary resilient coastal protection measures.

## Compliance with ethical standards

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