Leveraging the ASCE Infrastructure Report Card in the STEM Classroom

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Leveraging the ASCE Infrastructure Report Card and Economics Studies in the STEM Classroom

Abstract

Every four years, the American Society of Civil Engineers releases a national report card for America's infrastructure systems with the latest release occurring in March 2017. The Report Card provides not only an assessment of our infrastructure, but also an opportunity to engage and educate both the public and students in conversations about engineering. Beyond providing grades similar to a student's report card for 16 different categories of infrastructure across the country, the Report Card also addresses topics such as condition, capacity, resilience, and areas of innovation. Presented through a highly interactive website and mobile app, this can be a living tool for classroom conversations and investigations into engineering principles, design life, policy, and infrastructure systems. The Report Card, associated graphics and metrics, and the "grading" process itself can be utilized for students to begin inquiry-based learning through their own examination and evaluation of the infrastructure in their communities and beyond. This paper provides insight into the Infrastructure Report Card, how it was developed, and recommendations for utilization in the classroom. Examples include investigating infrastructure types (grades K-6), exploring local infrastructure and discussing safety, resilience and sustainability issues (grades 6-12), and exploring the economics of infrastructure (undergraduate engineering students).

Introduction

The American Society of Civil Engineers' national report card for America's infrastructure systems (hereafter referred to as the Report Card) provides an evaluation of the condition and status of 16 types of infrastructure taking into consideration condition, capacity, resilience and other factors in a simple format where grading occurs in a student's report card fashion. ASCE released its first Report Card in 1998 with revisions/updates occurring approximately every four years to keep the information timely and most beneficial to society. Additional, related materials developed in correlation with the Report Card include a *Failure to Act* series of studies on how infrastructure conditions affect the U.S. economy, and *Infrastructure Game Changers* that highlight innovative approaches to addressing infrastructure shortcomings. In this paper, we provide a review of these three resources to advance the understanding by educators and the public and suggest possible ways to utilize these in an educational setting from kindergarten to the university level through a series of examples.

History and Purpose of the Infrastructure Report Card

The American Society of Civil Engineers (ASCE), founded in 1852, is the country's oldest national civil engineering organization. It represents more than 150,000 civil engineers in private practice, government, industry, and academia who are dedicated to advancing the science and profession of civil engineering. ASCE is dedicated to advancing the profession of civil engineering as well as highlighting the need for infrastructure investment in our country. Once every four years, America's civil engineers provide a comprehensive assessment of the nation's

major infrastructure categories in ASCE's Infrastructure Report Card. Using a simple A to F school report card format, the Report Card provides a comprehensive assessment of current infrastructure conditions and needs, both assigning grades and making recommendations for how to raise them.

The concept of a report card to grade the nation's infrastructure originated in 1988 with the congressionally chartered National Council on Public Works Improvement report, *Fragile Foundations: A Report on America's Public Works*. In 1988, when *Fragile Foundations* was released, the nation's infrastructure earned a "C," representing an average grade based on the performance and capacity of existing public works.

When the federal government indicated they would not be updating the report after a decade, ASCE used the approach and methodology to publish the first *Report Card on America's Infrastructure* in 1998. With each new report in 2001, 2005, 2009, 2013, and now 2017, the methodology of the *Report Card* has been rigorously assessed so as to take into consideration all of the changing elements that affect America's infrastructure.

By using a school report card format that anyone can understand, ASCE's goal is to bring this information to key decision-makers, business leaders, and the informed public. In the last iteration, the *2017 Report Card for America's Infrastructure*, America's cumulative GPA for infrastructure received a D+, which is the same as it was in 2013 although grades improved in seven infrastructure categories. The *2017 Report Card* demonstrates that when investments are made and projects move forward, the grades rise. In addition to this national Report Card, ASCE's sections and branches also prepare state and regional Infrastructure Report Cards on a rolling basis, to localize these public education and advocacy efforts to the state and local levels. Nearly half of the states have a recent Report Card.

Infrastructure Categories, Grading Scale, and Key Criteria

The 16 categories graded in ASCE's Infrastructure Report Card include Aviation, Bridges, Dams, Drinking Water, Energy, Hazardous Waste, Inland Waterways, Levees, Parks, Ports, Rail, Roads, Schools, Solid Waste, Transit, and Wastewater.

The ASCE Committee on America's Infrastructure, made up of nearly 30 dedicated civil engineers from across the country with decades of expertise in all categories, volunteer their time to work with ASCE Infrastructure Initiatives staff to prepare the Report Card. Over the course of nearly two years, the Committee assesses all relevant data and reports, consults with technical and industry experts, and assigns grades using the following criteria:

- *Capacity*: Does the infrastructure's capacity meet current and future demands?
- *Condition*: What is the infrastructure's existing and near-future physical condition?
- *Funding*: What is the current level of funding from all levels of government for the infrastructure category as compared to the estimated funding need?
- *Future Need*: What is the cost to improve the infrastructure? Will future funding prospects address the need?

- *Operation and Maintenance*: What is the owners' ability to operate and maintain the infrastructure properly? Is the infrastructure in compliance with government regulations?
- *Public Safety*: To what extent is the public's safety jeopardized by the condition of the infrastructure and what could be the consequences of failure?
- *Resilience*: What is the infrastructure system's capability to prevent or protect against significant multi-hazard threats and incidents? How able is it to quickly recover and reconstitute critical services with minimum consequences for public safety and health, the economy, and national security?
- *Innovation*: What new, innovative techniques, materials, technologies, and delivery methods are being implemented to improve the infrastructure?

The grading scale used is as follows:

> *A: Exceptional, Fit For The Future*
> The infrastructure in the system or network is generally in excellent condition, typically new or recently rehabilitated, and meets capacity needs for the future. A few elements show signs of general deterioration that require attention. Facilities meet modern standards for functionality and are resilient to withstand most disasters and severe weather events.
>
> *B: Good, Adequate For Now*
> The infrastructure in the system or network is in good to excellent condition; some elements show signs of general deterioration that require attention. A few elements exhibit significant deficiencies. Overall, the infrastructure is safe and reliable, with minimal capacity issues and minimal risk.
>
> *C: Mediocre, Requires Attention*
> The infrastructure in the system or network is in fair to good condition; it shows general signs of deterioration and requires attention. Some elements exhibit significant deficiencies in conditions and functionality, with increasing vulnerability to risk.
>
> *D: Poor, At Risk*
> The infrastructure is in poor to fair condition and mostly below standard, with many elements approaching the end of their service life. A large portion of the system exhibits significant deterioration. Condition and capacity are of serious concern with strong risk of failure.
>
> *F: Failing/Critical, Unfit For Purpose*
> The infrastructure in the system is in unacceptable condition with widespread advanced signs of deterioration. Many of the components of the system exhibit signs of imminent failure.

The 2017 Report Card for America's Infrastructure

ASCE's *2017 Report Card for America's Infrastructure* was released in March 2017, once again leveraging a digital app developed for iPad, iPhone and Android platforms featuring animated

infographics, videos and state-specific data and placement of stories to make the information most readily available and applicable to the American public, as was done in 2013.

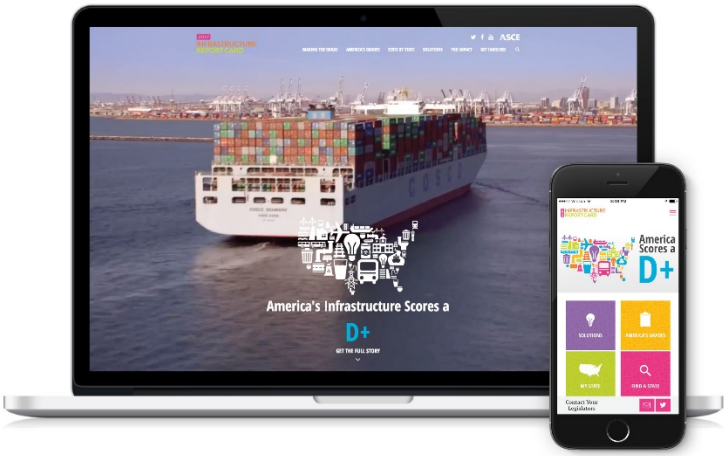

Figure 1: Sample of the displays of the 2017 Report Card on multiple devices

The Failure to Act Economic Study Series

ASCE's Infrastructure Report Card grades are a comprehensive assessment of infrastructure conditions across the United States. But what does D+ infrastructure mean for the nation's economy?

In 2011, ASCE commissioned a series of economic reports called Failure to Act, to provide an objective analysis of the economic implications for the U.S. on the current investment trends in key infrastructure sectors. In 2016, ASCE updated the series findings to reflect current conditions, *Failure to Act: Closing the Infrastructure Investment Gap for America's Economic Future* (available at http://www.asce.org/failuretoact/). These reports cover 10 of the 16 categories addressed by the Report Card for America's Infrastructure, and give specific figures on the cost of infrastructure inefficiencies, including the:

- cost to each family's disposable income,
- impact to American jobs,
- added cost to U.S. businesses, and
- overall impact to the U.S. economy.

Figure 2: Failure to Act: Closing the Infrastructure Investment Gap for America's Economic Future

The 2011 and 2012 infrastructure sector-specific reports of the Failure to Act series included:

- Surface Transportation (including roads, bridges, and transit),
- Water and Wastewater,
- Energy Transmission, and
- Airports, Inland Waterways and Marine Ports.

Infrastructure Game Changers

While all categories of American infrastructure require modernization and improvement, civil engineers, local communities, all levels of government, and the private sector have already started to develop innovative approaches to address our nation's significant infrastructure needs. To spotlight these efforts, ASCE seeks to continually identify infrastructure Game Changers – groundbreaking infrastructure projects and emerging trends that are transforming the way we plan and build projects across the country and the Report Card's 16 categories (available at http://ascegamechangers.org/).

Trends featured to date include:

- Ridesharing and transit apps
- Accelerated bridge construction
- Next generation pavements
- Robotic bridge inspection tools
- Coordinated saving
- Extracting energy from waste
- Recycled and reclaimed water
- LiDAR and drone technology
- E-construction

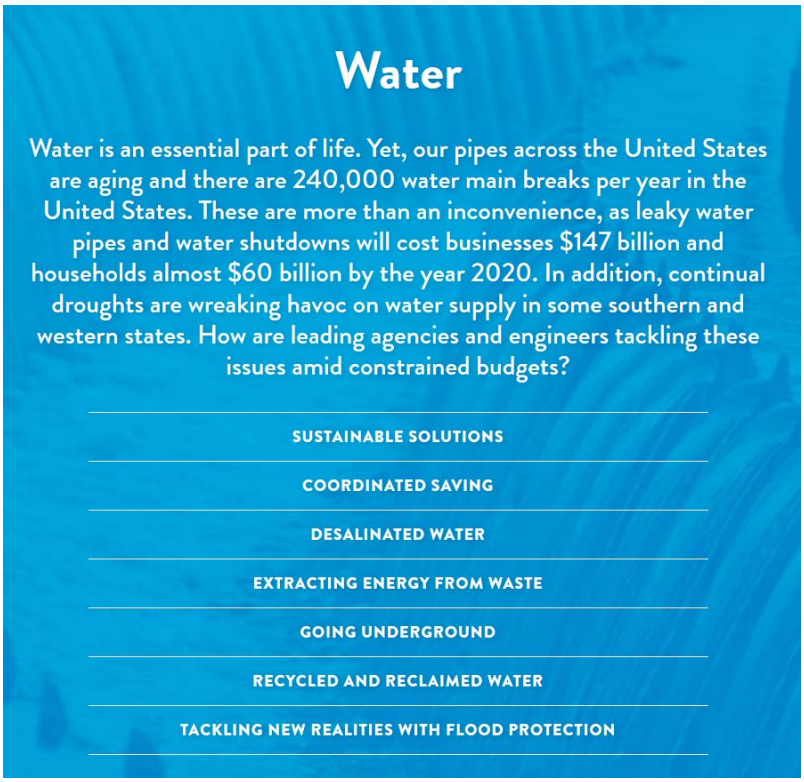

Figure 3: ASCE Game Changers' Topics Page on Water (http://ascegamechangers.org/topics/water)

Relevance for the STEM/Engineering Classroom

The *ASCE Infrastructure Report Card* describes many categories of infrastructure that engineers design, operate and maintain that are frequently out of daily sight for most individuals. The Report Card helps bring visibility and can be used to prompt exploration and classroom discussion about these infrastructure types, systems, and individual components to raise awareness among students.

The public typically views civil engineers as being the designers of transportation infrastructure such as roads and bridges, but civil engineering plays a role in many other types of infrastructure systems as indicated by the Report Card and in *Game Changers*. For example, much of our drinking water infrastructure is "hidden" from daily views and often taken for granted unless something goes awry beyond seeing the faucets delivering the water to its final destination or large water storage tanks in some areas. Additionally, a large number of Americans live behind earthen levees or floodwalls or downstream of a dam and may not realize that they are in a "protected" zone which otherwise would likely flood on regular occasion. Energy infrastructure is far more than just the power lines visible on one's daily travels, but also includes dams for hydropower generation as well as other complicated facilities including wind turbines which exist in some communities, but not others. The report card also brings to the forefront issues related to solid waste and hazardous waste management of which many may not realize that engineers play a critical role in designing landfills to ensure that contaminants are contained and/or treated on site.

Not only can exposure to the Report Card in the classroom prompt exploration into the different types of infrastructure that civil engineers play a critical role in development of, but the Report Card as well as the Game Changers (at times) can be used to challenge stereotypes about engineering as well as prompt exploration into careers that are associated with the different infrastructure types. Students may become interested in water quality or levees and begin investigating the different types of engineering involved or even the different sub-disciplines within civil engineering that may be involved. For instance, in the creation of levees, civil engineers involved may have specializations in hydrology (environmental engineering), soil compact-ability and soil types (geotechnical engineering), and the actual construction process of the levee (construction management).

Exposing students to the Infrastructure Report Card in the classroom also provides an opportunity to enhance student vocabulary and develop an understanding of the principles considered by engineers when assessing the infrastructure. Terms such as sustainability, resilience, and capacity are addressed in the Report Card assessments of the infrastructure categories as key criteria areas mentioned previously in this paper. In addition, the Report Card contains information and technical terminology relevant to the infrastructure types discussed such as design life, condition ratings, risk, etc. Teachers may have students explore the definitions of these terms to better understand what was considered in the grading and it may lead to student creation of a local report card for their school district or community by applying similar criteria to the infrastructure around them or assisting (in the case of college students) with an official ASCE Local or State Report Card.

Example Report Card Integration Activities for K-12 through College

The following sections present some example activities that teachers can do with their students to utilize the Report Card, supplementary materials such as the Failure to Act studies, and ASCE's educational outreach resources to enhance student learning. The sample activities are arranged in groupings by grade levels. Note that these are a small sample of what can be done and only provided as examples to begin the conversation and prompt some additional ideas and implementation by others.

The ASCE Pre-College Outreach website (http://www.asce.org/pre-college_outreach/) provides a number of resources and materials that are applicable at many age levels for teachers to utilize in their classrooms. Among the items on the website is a video titled "What Do Civil Engineers Do?" which exposes the viewer to three civil engineers and what they do in their work to improve lives of people every day. There is also a link to "It's Cool to be a Civil Engineer" which was adopted from the *Building Big: Thinking Big, Building Small* program complete with a video, background essay, and suggested discussion questions for a target audience of grades 3-8. The outreach website includes suggested hands-on activities, a link to a free bridge design and testing software website, a link to Streetmix street design software, ASCEville activities for grades 3-7, and at the bottom of the page, an infographic on the infrastructure we all typically use prior to noon each day as well as the Report Card. From the website, teachers can email ASCE staff requesting an engineer to visit their classroom as well. As one can see, there are many resources freely available for teachers (as well as engineers and parents).

Additionally, we would like to encourage teachers and professionals in engineering to reach out to each other. Classroom activities and student engagement can be greatly enhanced by bringing in engineers to talk to students about what they do and how they arrived in their position. Teachers can further benefit from asking local engineers to assist with the hands-on activities and/or classroom discussions about infrastructure including its design, maintenance, and operations. Engineers mutually benefit from classroom visits by inspiring the next generation of young, bright minds to consider engineering to help address the future challenges that we face with an aging infrastructure system and also further curating good stewards of the infrastructure that we have. This is in addition to helping to fill the gap that our nation is facing in the number of civil engineering jobs and lack of educated individuals to fill those jobs.

Grades K-6

As mentioned earlier, the Report Card can be used to broaden student views of civil engineering, raise awareness of the infrastructure in their community, and enhance vocabulary. At the younger levels, teachers may use the Report Card mobile app or website to assist students in exploring the photos and grades for infrastructure to raise awareness. Furthermore, depending on the location of the school, if a state or local report card exists in the area, teachers can lead student discussion about what types of infrastructure students see around them, what grades each received and why it received such a grade, diving into the text provided to explain the condition of the infrastructure. Teachers can also share with students the videos mentioned earlier from the ASCE Pre-College Outreach website and activities mentioned earlier.

Some questions that teachers may ask students when exploring the Report Card and related activities are as follows:

- Q: Which of these infrastructure types do you see and/or use in your daily activities?
    - Activities:
        - A discussion with students could include the infographic "How Much Infrastructure Do You Use Before Noon?"
        - Students choose one category of infrastructure to explore in more detail through creation of a short report, a photo collage of that infrastructure type (younger students),
        - Teachers lead a field trip around their community and have students identify the different infrastructure components around them; have students complete an infrastructure scavenger hunt where students take photos of the infrastructure they see on their daily travel to and from school with the assistance of a parent to take photos, etc.
- Q: Which of these infrastructure types did you not know existed before exploring the Report Card?
    - Activities:
        - Teachers lead a classroom discussion about which ones students are more familiar with and why (e.g., highway infrastructure vs. water infrastructure).

        - Teachers explain the water treatment process or other less visible/known infrastructure to expand student understanding.
- Q: What can we do to help take care of or improve our infrastructure?
    - Activities:
        - Teachers have students investigate ways to reduce waste, save electricity, and reduce water consumption.
        - Students log how much time they spend in the shower/bath and/or using water for other purposes to estimate their individual usage and multiply that by the number of people in their household, school, etc. to consider how much could be saved by reducing shower time, etc.
        - Teachers present portions of the *Failure to Act* series or associated infographics to help students understand the "cost" of infrastructure in poor condition or in need of repair as it applies to their family and communities.
        - Students take the per family costs mentioned in the Failure to Act studies and apply it through multiplication to their class as a whole and/or their school or community.
        - Use an exploration of *Game Changers* to lead student exploration of innovative solutions to engineering problems on a range of infrastructure types or near their community (when using the map view). Teachers may prompt students to come up with creative ideas to "solve" infrastructure problems in their communities and beyond using the *Game Changers* as examples of innovative solutions.
- Q: If you were going to grade our infrastructure systems (at the local, state or national level), what grade(s) would you give and why? Can you justify the grade(s) using similar criteria as in the Report Card?
    - Activities:
        - For older students, teachers assist in exploring why the various infrastructure categories received the grades that they did, bring in local infrastructure "experts" to assist with the discussion and assessment.
        - Additionally, depending on the infrastructure that is being considered, teachers review the references provided in the Report Card and expose students to charts/data (this meets math literacy requirements) to begin drawing conclusions on capacity and condition of systems. For example, the National Bridge Inventory, National Levee Database, U.S. Bureau of Transportation Statistics Annual Reports, etc. are all easily accessible public data sources.
- Q: Some infrastructure systems are interconnected. Can you identify which ones may be dependent or interrelated?
    - Activities:
        - Teachers ask leading questions to help students think through this problem such as "How do the pumps at a water treatment plant get the power to pump the water to the tanks and/or homes and businesses?"
        - Students develop an "infrastructure web" similar to a food web to visualize how infrastructure may be connected.

- Q: What would you tell others about the infrastructure in your community, your state, our nation?
    - Activities:
        - Teachers have students develop a poster, report, or video to address the question and communicate what they have learned.
        - Teachers utilize the *Failure to Act* series to expand upon students' understanding of the implications of infrastructure condition on their family and their communities. Exploration of the infographics that summarize the study into the cost per household of traffic delays, etc. can be used by students to tell their stories about infrastructure at a local level.

Grades 6-12

At the high school level, simple awareness and recognition of the infrastructure types and issues take on a more in-depth investigation involving data analysis and understanding of the grading criteria. Similar to lower grades but at a deeper level of engagement, middle and high school students can address the questions presented above in addition to those below, and engage in related activities.

- Q: Can you identify local infrastructure for each of the 16 categories and how would you assess its condition and capacity?
    - Activity:
        - As with elementary grades, a field trip, scavenger hunt, or student exploration activity would be appropriate here, but it should be more involved such as identifying which roadways are typically congested (or at capacity) during high traffic periods of the day.
- Q: What is resilience? What does it mean with regards to infrastructure? Can you identify any efforts to create resilience or "harden" infrastructure in your community? If so, what is being protected and how?
    - Activity:
        - Teachers ask students to review local news reports, interview infrastructure managers (i.e., engineers working on specific projects or representing different infrastructure types).
        - Teachers ask students to consider any natural disasters that have happened in the area historically and what was done prior to and following the disaster to protect citizens using infrastructure systems.
- Q: What can be done to improve or protect our infrastructure without requiring a lot of money or doing things as we have always done before? What are possible innovations mentioned in the Report Card and/or Game Changers that can be utilized in our community?
    - Activity:
        - Teachers have students peruse the Report Card and Game Changers to identify innovations mentioned and investigate further. What was the problem trying to be solved? How did the innovation help? What similar issues exist in the local community that may require innovative solutions and can we come up with such solutions?

- Q: If you were going to grade our infrastructure systems (at the local, state or national level), what grade(s) would you give and why? Can you justify the grade(s) using similar criteria as in the Report Card?
    - Activities:
        - Teachers can assist students in exploring why the various infrastructure categories received the grades that they did, applying the state report card rubrics to grade their infrastructure, and bring in local infrastructure "experts" to assist with the discussion and assessment. Students can reach out to utilities and others to gather data and analyze the data to develop grades for the infrastructure.
        - Additionally, depending on the infrastructure that is being considered, teachers may look at the references provided in the Report Card and expose students to charts/data (this meets math literacy requirements) to begin drawing conclusions on capacity and condition of systems. For example, the National Bridge Inventory, National Levee Database, U.S. Bureau of Transportation Statistics Annual Reports, etc. are all easily accessible public data sources.
- Q: Some infrastructure systems are interconnected. Can you identify which ones may be dependent or interrelated?
    - Activities:
        - Teachers invite engineers into the classrooms to dive into the subject of "systems" and "networks" to discuss how individual infrastructure components are interconnected.
        - Students can develop models and/or diagrams to demonstrate how infrastructure components and systems may be interconnected.

College Undergraduates

At the baccalaureate level, engineering students are exposed to a number of topics and concepts that relate to infrastructure conditions. Once they enter the workforce, civil engineering graduates are likely to be working on many of the projects and issues outlined in the Report Card and a working knowledge of the complexities that affect infrastructure design and delivery is valuable to any civil engineer. Civil engineering curricula could benefit from the addition of "real world" examples to enhance the educational experience for undergraduates, and satisfy ABET criteria.

Economic Issues

The infrastructure challenges raised by the Report Card and *Failure to Act* studies have hefty price tags attached to them. The *Failure to Act* studies and infographics can be used to prompt and investigate life-cycle cost discussions with students. Students can dive into analysis on the local and regional implications with the projected needs as well as investigate savings of innovative solutions to congestion such as ride-sharing and public transit. Students can perform analyses of the national data sets referenced in the Report Card to arrive at their own grades. Additionally, students can develop arguments based upon analysis of the data presented in the *Failure to Act* studies on the benefits of investing in some infrastructure improvements now to reduce costs and damages in the future.

Resilience & Sustainability
Resilience and sustainability are also key concepts that should be incorporated into baccalaureate studies. Students may investigate and evaluate how a slightly greater investment in today's dollars to "harden" or improve infrastructure may allow it to last longer and withstand more damages under future conditions. Practical examples of this include: use of carbon fibers or nanomaterials in construction, smart technology for monitoring and inspections, putting in larger culverts now to reduce potential roadway damages due to heavy flash flooding events in the future. Innovation is central to many college engineering programs today with the Maker Movement and the ASCE Game Changers can be used as examples of innovations to spur student creativeness.

Any of these suggestions could be incorporated into an engineering capstone or senior design course and some have potential for freshman introduction to engineering course work (e.g., exploration of the infrastructure types as an introduction to careers in engineering or a review of the Game Changers to showcase engineers as problem solvers and innovators). Use of the Failure to Act studies as part of life cycle cost analysis in engineering mathematics, design, and/or economics courses within an engineering program provides hands-on, real-world exposure to applications of these concepts. These can be used to help meet or enhance ABET-accredited curriculum goals to "prepare students for engineering practices while incorporating appropriate engineering standards and multiple realistic constraints" (i.e., funding limitations and considerations for the life span, maintenance, and operating costs of infrastructure assets). Additionally, student outcomes that can be enhanced through exposure to the Report Card and economic studies in activities such as those suggested for ABET accreditation include (1) an ability to analyze and interpret data; (2) apply knowledge of math, science, and engineering; (3) and an ability to identify, formulate, and solve engineering problems, which in this case are problems associated with improving the deteriorating condition and lack of funding for of our infrastructure systems (ABET 2016).

Capstone/Senior Design Courses
The intent behind senior design capstone courses is to introduce students to an engineering problem and challenge them to design a solution. One of the challenges facing instructors is to devise a problem that the solution is not already clearly defined. In many cases, students examine a structure or system that is already built, and work through how it addressed the problems encountered. Using conditions outlined in the Report Card, students could be assigned to design a solution to an infrastructure failure or breakdown that isn't already built and implemented.

Concepts in the Report Card and Failure to Act studies also represent opportunities to introduce interdisciplinary elements to engineering students, such as economics, public policy/political science, and sociology. For political science, questions such as "How do we determine needs and set priorities?" For economics, "How do we finance infrastructure improvement and construction projects?" For sociology, "How do we anticipate the infrastructure needs of a community for 10, 20, or 50 years from now?" and "How do we influence society's use of infrastructure systems to extend life cycles or mitigate deterioration?" Exploring these various aspects and how engineering design relates to them will better equip graduates to design systems that will effectively serve the public. In their paper on teaching infrastructure courses, Schmucker et al

noted that, “Within this practice [of studying civil infrastructure systems] is a recognition of the role that systems play in societal functioning while accounting for how human behavior and social organizations contribute to and affect the performance of a given system. When students are taught this perspective of infrastructure, they are often more proficient in their efforts to incorporate all of the stakeholders in the development and implementation of the facilities and processes they are asked to study.” Tools such as the Report Card and economic studies can be invaluable in demonstrating these links to students, and driving home the importance of concepts such as sustainability and resilience (Schmucker et al., 2016).

Conclusion

Here, we have presented an overview of the ASCE Infrastructure Report Card and other affiliated infrastructure information resources that teachers can utilize in the classroom. We have also presented several examples of how teachers could utilize these resources coupled with additional pre-college resources from the ASCE website. To date, we do not have well documented case studies or in-class examples of these activities being put into practice, but hopefully that will come as more engineers and teachers become aware of the opportunities to utilize the Report Card and other reports to enhance student learning about engineering.

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