Science investigation and engineering design: The seven sectors of stem solutions

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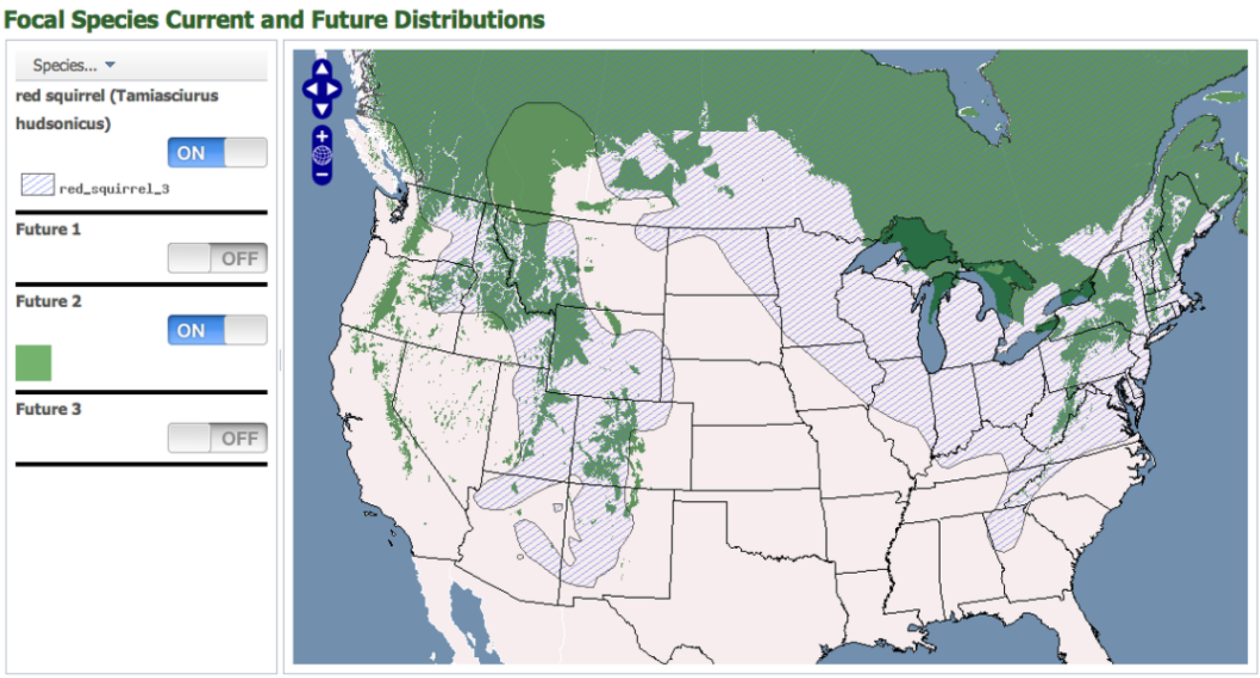
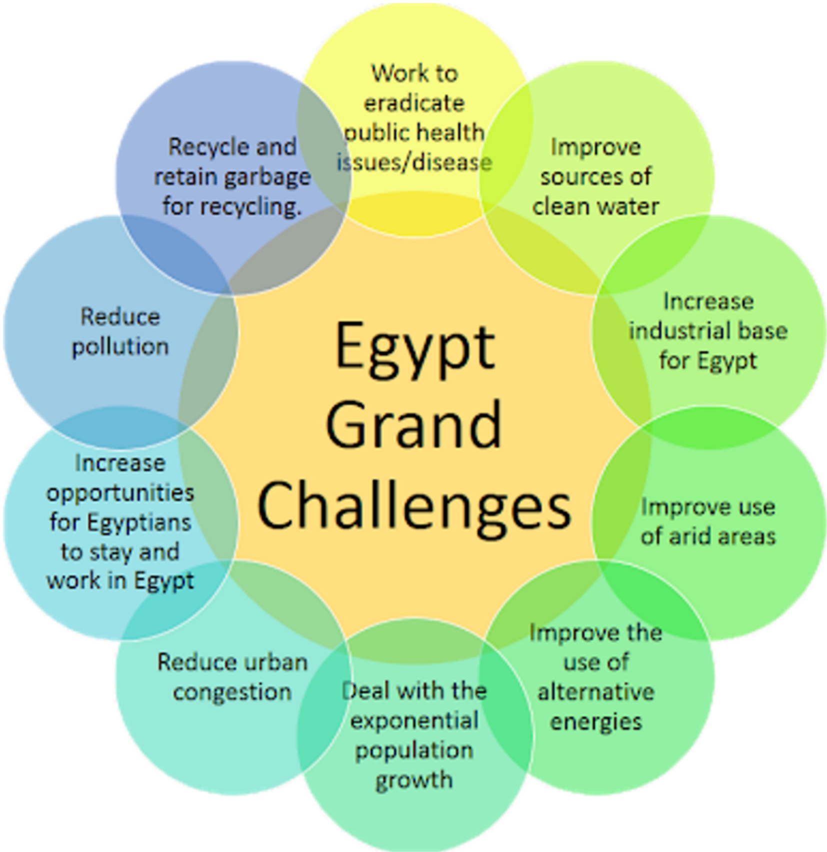


Figure: Present(hashed) and future (solid) scenarios for the distribution of the red squirrel

Nancy Butler Songer, the Associate Provost of STEM Education at the University of Utah, focuses on science investigations and engineering design relevant to our complex world by identifying the Seven Sectors of STEM Solutions

"The headlines in the State of the Climate Update 2024 give cause for great concern. Greenhouse gas concentrations continue to steadily rise, driving further long-term temperature increases, highlighting the rapid changes in our climate system in the space of a single generation. Every fraction of a degree of warming matters to our planet, to our lives, to future generations" (World Meteorological Organization, 2024; p. 2).

We are faced with a multitude of complex, interdisciplinary challenges with foundations in science, technology, engineering, and mathematics (STEM) disciplines. Drawing from over two decades of research and development of STEM education programs for adolescents ages 10-15, we have realized seven essential components of learning environments to guide adolescents towards the design of solutions to local environmental challenges. We call these the Seven Sectors of STEM Solutions.



1. A spine is a particular phenomenon with local relevance for context and meaning. The spine is the focus of all instructional, assessment, and professional learning activities and provides motivation for students to realize that their learning has value. In our USAID-funded program in Egypt (Merlino & Pomeroy, 2024), the spine was one of Egypt's Grand Challenges that was the focus of students' semester-long capstone project. For example, to address the Grand Challenge of reducing pollution, students designed and built methane sensors for local garbage cans in Cairo and a mobile app to direct garbage collectors to prioritize waste cans that generated the highest methane levels.
2. Products of learning need to have a purpose or substance, and an audience of supporters. Across our instructional programs, we design activities that empower adolescents to provide solutions and share their insights with local stakeholders, including scientists, community members, and government organizations. Focusing activities around local issues causes many aspects of classroom activities to differ from those commonly found in traditional classrooms. For example, instead of student work leading to knowledge of vocabulary or facts, student work in our programs leads to students' understanding of the natural and engineered world. Students acknowledge the value of learning when they state, "We are solving Egypt's problems."

3. Learning has to be appropriately challenging, with the ability to manage struggle. In our programs, the role of teachers shifts to a guide and partner in sensemaking discussions. For example, when the class discusses what is evidence, the conversation discusses where the evidence comes from, how this evidence matches the scientific question, and how the concept of evidence differs from other similar ideas, such as data. Often, these conversations also include appropriate guidance, such as hints or scaffolds.
4. Students practice synergy when they work as teams and draw from multiple sources to design solutions. For example, in one program focused on the design of traps to mitigate the population of local invasive insects, students create at least three designs for their trap, followed by peer critique to evaluate the effectiveness, creativity, and ease of repairs. In this way, students model problem-solving and critique, which is common among professionals.
5. Learning recognizes intermediate indicators of progress and the assessment of learning steps versus endpoints. In our programs, students have many opportunities to provide evidence of their progress and the places where their efforts fall short. Students and teachers have multiple opportunities to check for understanding and to provide scaffolds or guidance. Project work is also valued highly. For example, in Egypt, the student capstone projects count for 60% of the semester grade.

	Population growth rate	Energy use per person	Proportion clean energy	Total CO_2 emissions by 2100 (gigatons)
Future 1	Fast	Low	Low	1862
Future 2	Slow	High	High	1499
Future 3	Slow	Low	High	983

Figure: Intergovernmental Panel on Climate Change futures (simplified)

6. Professional scientists, engineers, and educators must collaborate to strategically simplify tools that support adolescent problem-solving. Strategic simplification recognizes the necessity of carefully selecting factors in the complex problem context for simplification without introducing errors. This simplification also allows adolescents to grapple with the problem and realize possible fruitful solutions. An example is our climate change impact curriculum that applied simplified Intergovernmental Panel on Climate Change (IPCC) future scenarios to a modeling program to view current and future distributions of animal species. Our team partnered with IPCC scientists to create a simplified version of their future scenarios (figure). Then, students used a simplified predictive distribution modeling tool to make predictions about where organisms may be able to live in the year 2100 under different futures with variations in population growth rate, energy use per person, proportion of clean energy, and total carbon dioxide emissions.

7. To realize systemic change, teams must sustain partnerships, funding, and learning activities over years or even decades. Instructional materials must sustain students' learning over several weeks or months to have multiple exposures and sustained engagement in sensemaking. Our curricular programs follow sequences outlined in educational vision documents (e.g., NRC, 2012) with activities that toggle between multiple rounds of science investigation activities (e.g., data collection, analysis, and argument construction) and engineering design (e.g., design and building of solutions).

This sequencing supports adolescents' mirroring of the work of scientists and engineers in practicing fluid and iterative design to realize a well-designed solution. Teachers' learning is also sustained over units and years so that teachers can take risks and make iterative improvements. Financial investments must be maintained to test, improve, and stabilize ideas.

Future of STEM

As the world's challenges with STEM foundations are complex, we must provide many varied opportunities for adolescents before college or professional careers to engage with and practice iterations of scientific investigation and engineering design towards the design of solutions. Programs of this kind require thinking beyond traditional approaches and narrow boundaries of science learning. Such thinking is crucial for all our futures.

References

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