Learning Through Making:
Young visitors at the Science Museum of Minnesota use a paint set of acids and bases to learn about pH as they create artistic compositions.
The FabLab Classroom provided elementary and middle school students with fabrication technologies such as 3-D printers and computer-controlled die cutters. The students learned science through engineering design using these advanced manufacturing technologies.

The Commonwealth of Virginia provided seed funding to design a lab school for advanced manufacturing. The school will serve as a lab for integrating engineering design into science teaching while also serving as an experimental platform for preparing the next generation of science teachers to use these technologies.
Learning Through Making

A volunteer at the Science Museum of Minnesota helps a young girl play a driving simulation that was created by a youth in a video game class at the museum with the Scratch program. Scratch is a very accessible programming environment that SMM uses to teach computer programming in classes that incorporate sensors and motors so that youth can create their own video game controllers as well as the games themselves.
Improving STEM Education Through Research: NSF-EHR Perspective

Ferdie Rivera, PhD
Intermittent Expert/Part-time Program Director
Division of Research on Learning (DRL)
Directorate for Education and Human Resources (EHR Directorate)
National Science Foundation
“For purposes of carrying out STEM education activities at the National Science Foundation, the Department of Energy, the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the National Institute of Standards and Technology, and the Environmental Protection Agency, the term “STEM education” means education in the subjects of science, technology, engineering, and mathematics, including computer science.”
NSF Directorates

- Biological Sciences
  - Computer and Information Sciences and Engineering
  - Social, Behavioral, and Economic Sciences
- Geosciences
  - Mathematics and Physical Sciences
  - Engineering
- Education and Human Resources
Nature of Research (Stokes):

More and more technology will be science-based, and more and more science will be technology-based.
The Directorate for Education and Human Resources: Building the STEM workforce of tomorrow and a STEM literate public by improving STEM learning.
STEM Professionals

T-shaped

Pi-shaped

Comb-shaped
EHR Directorate

- Division of Undergraduate Education (IUSE; ATE; NOYCE; STEM-C; REU)
- Division of Graduate Education (GRFP)
- Division of Human Resource Development (CREST; AGEP; EASE; HBCU; GSE; RDE; LSAMP; TCUP)
- Division of Research on Learning (CORE; ITEST; DR K 12; AISL; STEM-C)
Shifts in Education and Human Resources Investment 2006-Present

- **Non-Investment Activities**
- **Education and Training**
- **Research and Development**

Year:
- 2006: 9.25%
- 2010: 13.49%
- 2012: 30.33%
- 2014: 39.77%
- 2015*: 44.78%

* 2015 is the only figure represented by an estimate. All other figures are actuals.
Reflections on STEM R & D

• It is essential to have a coherent and deep scientific research base that informs/guides efforts to meet national STEM education and workforce development needs/priorities

• Need CORE research projects that address broad, essential, enduring, and challenges of great importance and are designed to inform the transformation of STEM learning and education

• Continue to support research projects that are potentially transformative and innovative
NSF EHR Core

- STEM Learning
- STEM Learning Environments
- STEM Workforce Development
- Broadening Participation in STEM
STEM Learning

• Learning of specific STEM disciplinary knowledge and practices across different groups of learners, contexts, and environments
• Learning includes cognitive, social and behavioral competencies
• Range of theoretical and methodological approaches, including the use of “big data”
• Focus on learning at the frontiers of STEM disciplines and interdisciplinarity
STEM Learning Environments

- Range of formal and informal learning environments across the K-16 landscape
- Develop an understanding of how characteristics of learning environments interact with or support multiple aspects of STEM learning
- Special focus on emerging learning environments and evidence-based approaches to undergraduate STEM instruction
- Multiple theoretical and methodological perspectives
**STEM Workforce Development**

- Preparation of a diverse, globally-prepared and highly-skilled STEM workforce - including teachers
- Focus on entire STEM workforce continuum, from Pre-K to postdoctoral training to career
- Emphasis on academic and non-academic STEM career pathways and transitions across changing contexts and climates
- Connecting workplace expectations to design of interventions
Broadening Participation in STEM

• Practices that broaden participation, retention, and success of individuals underrepresented in STEM
• Preparing students for successful transition to further education or training, or the STEM workplace
• Study of accessibility and the impacts of technology on diverse populations
• Measures, processes and metrics to assess impacts and outcomes of broadening participation and institutional capacity building (e.g. on STEM innovation/productivity)
NSF Review Criteria

• All proposals are evaluated against the two NSB-approved review criteria:
  • Intellectual Merit: criterion encompasses the potential to advance knowledge
  • Broader Impacts: criterion encompasses the potential to benefit society and contribute to the achievement of specific, desired societal outcomes
1. What is the potential for the proposed activity to:
   • **Advance knowledge** and understanding within its own field or across different fields (Intellectual Merit); and
   • **Benefit society** or advance desired societal outcomes (Broader Impacts)?

2. To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?

3. Is the **plan** for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to **assess** success?

4. How **well qualified** is the individual, team, or organization to conduct the proposed activities?

5. Are there **adequate resources** available to the PI (either at the home organization or through collaborations) to carry out the proposed activities?
Additional Proposal Considerations

• **Project evaluation**
  • Evaluation plan appropriate to project goals and descriptive of project assessment approach
  • Substantive external expert review mechanism

• **Project personnel and management**
  • Research and management roles of senior personnel
  • Roles and responsibilities of students and other trainees
  • Mentoring plan for postdoctoral researchers

• **Dissemination strategy**
Additional Proposal Considerations

• Letters of agreement to participate
  • All appropriate organizations
  • Members of advisory committees

• Research design and methodology
  • Appropriate and rigorous research methods
  • Well-documented usable, and replicable models, frameworks, data, literature, and measures
  • Well-justified methods, consonant with theory, and suited to the stated questions or hypotheses
Discovery Research K-12

• Enhance the learning and teaching of STEM by PreK-12 students and teachers, through research and development of STEM education innovations and approaches.

• Projects in the DRK-12 program build on fundamental research in STEM education and prior research and development efforts that provide theoretical and empirical justification for proposed projects.

• Projects should result in research-informed and field-tested outcomes and products that inform teaching and learning.

• Teachers and students who participate in DRK-12 studies are expected to enhance their understanding and use of STEM content, practices and skills.
Advancing Informal STEM Learning (AISL)

• Advance new approaches to and evidence-based understanding of the design and development of STEM learning opportunities for the public in informal environments
• Provide multiple pathways for broadening access to and engagement in STEM learning experiences;
• Advance innovative research on and assessment of STEM learning in informal environments.
STEM+Computing Partnerships

• Enhance the learning and teaching of STEM and computing by K-12 students and teachers through research on, and development of, courses, curriculum, course materials, pedagogies, instructional strategies, models, or pedagogical environments that innovatively integrate computing into one or more other STEM disciplines, or integrate STEM content into the teaching and learning of computing.

• Build capacity in K-12 computing education with foundational research and focused teacher preparation. Pre- and in-service teachers who participate in STEM+C projects are expected to enhance their understanding and teaching of STEM and computing content, practices, and skills.
EHR Core Research (ECR)

• Addresses fundamental research in STEM education in critical research areas that are essential, broad and enduring.
• Synthesize, build and/or expand research foundations in the following focal areas: STEM learning, STEM learning environments, STEM workforce development, and broadening participation in STEM.
Innovative Technology Experiences for Students and Teachers (ITEST)

• Promotes PreK-12 student interests and capacities to participate in STEM and information and communications technology (ICT) workforce of the future.

• supports the development, implementation, and selective spread of innovative strategies for engaging students in experiences that: (1) increase student awareness of STEM and ICT careers; (2) motivate students to pursue the education necessary to participate in those careers; and/or (3) provide students with technology-rich experiences that develop their knowledge of related content and skills (including critical thinking skills) needed for entering the STEM workforce.
Improving Undergraduate STEM Education (IUSE)

• Addresses immediate challenges and opportunities that are facing undergraduate STEM education and anticipate new structures (e.g. organizational changes, new methods for certification or credentialing, course re-conception, cyberlearning, etc.) and new functions of the undergraduate learning and teaching enterprise.

• The IUSE: EHR program recognizes and respects the variety of discipline-specific challenges and opportunities facing STEM faculty as they strive to incorporate results from educational research into classroom practice and work with education research colleagues and social science learning scholars to advance our understanding of effective teaching and learning.
Common Guidelines for Education Research and Development


U.S. National Science Foundation and U.S. Department of Education
What do we mean by “Common Guidelines?”

A cross-agency framework that describes:

• Broad types of research and development

• The expected purposes, justifications, and contributions of various types of research to knowledge generation about interventions and strategies for improving learning
A
Core Knowledge
- Foundational Research
- Early Stage & Exploratory Research

B
Design & Development Projects

C
Impact Evaluations
- Efficacy Studies
- Effectiveness Studies
- Scale-up Studies

Knowledge & Evidence Resources
CORE KNOWLEDGE

• Foundational Research
• Exploratory/Early Stage Research
Foundational Research

Fundamental knowledge that may contribute to improved learning & other education outcomes

Studies of this type:

○ Test, develop or refine theories of teaching or learning
○ May develop innovations in methodologies and/or technologies that influence & inform research & development in different contexts
Early-Stage or Exploratory Research

- Examines relationships among important constructs in education and learning
- Goal is to establish logical connections that may form the basis for future interventions or strategies intended to improve education outcomes
- Connections are usually correlational rather than causal
Design and Development Research
Design and Development Research

- Draws on existing theory & evidence to design and iteratively develop interventions or strategies
  - Includes testing individual components to provide feedback in the development process
- Could lead to additional work to better understand the foundational theory behind the results
- Could indicate that the intervention or strategy is sufficiently promising to warrant more advanced testing
STUDIES OF IMPACT

• Efficacy Research
• Effectiveness Research
• Scale-Up Research
Studies of Impact generate reliable estimates of the ability of a fully-developed intervention or strategy to achieve its intended outcomes

Efficacy Research tests/examines whether an intervention or strategy can improve outcomes under what are sometimes called “ideal” conditions

Effectiveness Research tests/estimates the impacts of an intervention or strategy when implemented under conditions of routine practice

› Scale-Up Research examines/estimates the impacts of an intervention or strategy under conditions of routine practice and across a broad spectrum of populations and settings
## Important Features of Each Type of Research

<table>
<thead>
<tr>
<th></th>
<th>Purpose</th>
<th>Justification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Purpose</strong></td>
<td>How does this type of research contribute to the evidence base?</td>
<td>How should policy and practical significance be demonstrated?</td>
</tr>
<tr>
<td><strong>Justification</strong></td>
<td></td>
<td>What types of theoretical and/or empirical arguments should be made for conducting this study?</td>
</tr>
<tr>
<td>Outcomes</td>
<td></td>
<td></td>
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<tr>
<td>----------------</td>
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<tr>
<td>Generally speaking, what types of outcomes (theory and empirical evidence) should the project produce?</td>
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<tr>
<td>What are the key features of a research design for this type of study?</td>
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</tbody>
</table>
## Comparison, in brief: JUSTIFICATION

<table>
<thead>
<tr>
<th>Exploratory/Early Stage Research</th>
<th>A clear description of the <em>practical education problem</em> and a compelling case that the proposed research will inform the development, improvement, or evaluation of education programs, policies, or practices</th>
</tr>
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<td>A strong <em>theoretical and empirical rationale</em> for the project, ideally with citations to evidence</td>
</tr>
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## Comparison, in brief: JUSTIFICATION

<table>
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<tr>
<th>Design and Development Research</th>
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<tr>
<td>‣ A clear description of the <em>practical problem</em> and the initial concept for the planned investigation, including a well-explicated <em>logic model</em></td>
</tr>
<tr>
<td>‣ In the logic model, identification of <em>key components of the approach</em>, a description of the relationships among components, and <em>theoretical and/or empirical support</em></td>
</tr>
<tr>
<td>‣ Explanation of how the approach is different from current practice and why it has the potential to improve learning</td>
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### Comparison, in brief: JUSTIFICATION

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<tr>
<th>Efficacy Research</th>
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<tbody>
<tr>
<td>▶ Clear description of the intervention/strategy and the <em>practical problem</em> it addresses; how intervention differs from others; and connection to learning</td>
</tr>
<tr>
<td>▶ <em>Empirical evidence of promise</em> from a Design and Development pilot study, or support for each link in the logic model from Exploratory/Early Stage research, <em>or evidence of wide use</em></td>
</tr>
<tr>
<td>▶ Justification for examining impact under ideal circumstances, rather than under routine practice conditions</td>
</tr>
</tbody>
</table>
Comparison, in brief: OUTCOMES

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<th>Exploratory/Early Stage</th>
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<tr>
<td><strong>Empirical evidence</strong> regarding associations between malleable factors and education or learning outcomes</td>
</tr>
<tr>
<td><strong>A conceptual framework</strong> supporting a theoretical explanation for the malleable factors’ link with the education or learning outcomes</td>
</tr>
<tr>
<td><strong>A determination</strong>, based on the empirical evidence and conceptual framework, of whether Design and Development research or an Efficacy study is warranted, or whether further Foundational or Exploratory/Early-Stage research is needed</td>
</tr>
</tbody>
</table>
Comparison, in brief: OUTCOMES

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<thead>
<tr>
<th>Design and Development Research</th>
<th>Design and Development Research</th>
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<tr>
<td>A fully-developed version of the intervention or strategy</td>
<td>A well-specified logic model</td>
</tr>
<tr>
<td>Descriptions of the major design iterations, resulting evidence, and adjustments to logic model</td>
<td>Measures and data demonstrating project’s implementation success</td>
</tr>
<tr>
<td>Pilot data on the intervention’s promise for generating the intended outcomes</td>
<td></td>
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</table>
## Comparison, in brief: OUTCOMES

<table>
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<td>Detailed descriptions of the study goals, design and implementation, data collection and quality, and analysis and findings</td>
</tr>
<tr>
<td>Implementation documented in sufficient detail to judge applicability of the study findings; when possible, relate these factors descriptively to the impact findings</td>
</tr>
<tr>
<td>Discussion of the implications of the findings for the logic model and, where warranted, make suggestions for adjusting the logic model to reflect the study findings</td>
</tr>
</tbody>
</table>