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Understanding Federal STEM Education Initiatives

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Abstract

Unsurprisingly, the United States government actively recognizes the need to support initiatives in Science, Technology, Engineering, and Mathematics (STEM) education in order to remain a global leader in discovery and innovation. For this reason, the National Science and Technology Council's (NSTC) Committee on STEM Education (CoSTEM) released a five-year strategic plan in 2018 describing nation-wide goals surrounding STEM education and the strategic pathways through which these goals could be achieved. It is this strategic plan that recognizes that even though increased financial support is helpful, collaboration, purposeful program development, and investment transparency are also key to achieving the goals set forth in the plan. Through an analysis of the Federal STEM ecosystem, the work reported by interagency working groups within CoSTEM, and the Federal STEM Investments Inventory data, which has been made publicly available via annual progress reports, we provide insight into how Federal STEM education efforts have made progress towards its three goals of improved STEM literacy, increased diversity, equity, and inclusion (DEI), and STEM workforce development. Additionally, we consider what this analysis means in the context of the greater STEM community. With the STEM Education Strategic Plan's tenure coming to an end, this paper concludes by encouraging discussion regarding the future of Federal STEM education initiatives informed by the last five years' progress and potential shortcomings.

1 Introduction

"Science, technology, engineering, and mathematics (STEM) are the foundation for discovery and innovation." This is the first line of the introduction for the three most recent progress reports on the implementation of the STEM Education Strategic Plan published by the United States' National Science and Technology Council (NSTC) in 2018.[1,2,3] In following the same sentiment, assessments of national capabilities often look at a population's qualifications in STEM subjects. One example is the Global Innovation Index, which considers the percentage of a country's post-secondary graduates whose degrees qualify as STEM as one of its 80 indicators when evaluating a country on innovation.[4] It should come as no surprise then that effective STEM education is conventionally considered a priority for nations who wish to remain innovative and competitive economically. The question then remains, what exactly does it mean to be effective at STEM education as a nation?

Most certainly, the answer to that question includes educating and training a capable STEM workforce. Effective STEM education will absolutely need to create opportunities for students to grow into the innovators, entrepreneurs, scientists, researchers, and CEOs that propel a nation towards new ideas and economic outputs. This includes ensuring a certain level of quality in STEM education as well as maintaining an appropriate quantity of STEM-trained graduates. According to the Global Innovation Index, one of the United States' weaknesses in innovation is in the quantity of STEM-trained graduates and not necessarily the quality of their education. In fact, the United States ranks first globally in terms of the quality of education provided by its universities according to the QS World University Rankings.[5] As for quantity, though the U.S. has demonstrated growth in its percentage of STEM graduates by +2.7% since 2018, it still trails the two highest ranking countries, Switzerland and Sweden, by 5.1% and 6.9%.[4]

Aside from training the engineers that will enable fully autonomous vehicles to become a reality, effective STEM education will equally require the general population to become better educated in STEM topics such that they can appropriately interact with and hold accountable those very same autonomous vehicles. In other words, effective STEM education must include creating a STEM literate society. Understanding how equipped an adult population is to participate in an economically prosperous society is exactly what the Program for the International Assessment of Adult Competencies (PIAAC) was developed to investigate in 2011. Naturally, one measure of the key cognitive and workplace skills that the PIAAC evaluates is therefore the ability to "problem solve in a technology rich environment."[6] Many, including the U.S. Department of Education (ED) refer to this as digital literacy, which is considered a component of STEM literacy.

At the conception of the NSTC's STEM Education Strategic Plan in 2018, results of the PIAAC suggested that only 76% of U.S. adults could go beyond the simplest forms of reasoning when assessed on digital literacy. By the PIAAC's standards, this means that 24% of adults likely could not do much more than assign items to categories when problem solving in a digital environment. Furthermore, the PIAAC found that only 6% of U.S. adults could conduct tasks that require evaluating the relevance and reliability of information in order to discard distractors, a skill associated with the PIAAC's level 3 of proficiency.[7] This suggests that only 6% of U.S. adults could be expected to accurately interpret and make use of the massive amounts of data being revealed to them via social media every time they unlock their phone. Though these results were gathered in 2017, these are the most recent measures on U.S. adult digital literacy until the second cycle of the PIAAC is completed in future years.

Regardless, our world is continuously advancing and evolving. In large part, this is thanks to advances made in STEM. Our government leaders and advisors openly acknowledge this fact. The bipartisan CHIPS and Science Act of 2022 is a key example of this as it allocates historically large investments to be given to U.S. workers, communities, and businesses with the goal of ensuring that the United States is a leader in the "industries of tomorrow".[8] The NSTC's 2018 STEM Education Strategic Plan (STEM-Ed SP) subsequently proves vital as it not only further exemplifies the desire for our nation to proactively achieve effective STEM education at a whole-of-nation level but also provides a route through which it could be better achieved.

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2 Purpose

Because the NSTC's 2018 STEM-Ed SP was designed to have a five year reach spanning from 2018 to 2023, it is now an appropriate time to assess the progress made in STEM education and open a discussion on what lessons have been learned. The purpose of this paper is to convey the takeaways of our data-driven analysis of the 2018 NSTC's STEM-Ed SP using insights gained from understanding the Federal STEM education ecosystem. In doing so, we aim to build a greater public understanding of the progress made and identify potential shortcomings.

In evaluating the progress of this strategic plan, we must keep in mind the plan's primary goals. The three goals outlined in the STEM-Ed SP are

1. Establish a strong foundation for STEM literacy.
2. Prepare the STEM workforce for the future.
3. Increase diversity, equity, and inclusion in STEM.

In this paper, effective STEM education efforts are therefore defined as efforts that have maximally achieved these goals. For metrics in evaluating such progress in these areas, we first looked to the progress reports to identify what the NSTC defined as success. In the absence of clear metrics, we pivoted to discuss how success may be inferred when analyzing the data available.

To begin, we first share a summary of the Federal STEM education ecosystem in Section 3. We then provide a thorough assessment of the Federal STEM education data available in Section 4. The primary sources of data used in this analysis are the annual updates to the STEM Investments Inventory, which are found at the end of the 2019, 2020, 2021, and 2022 progress reports on the implementation of the STEM-Ed SP. In addition to analyzing this repository of investments, we also discuss the wider-spanning initiatives that were carried out by interagency working groups as a result of the STEM-Ed SP. Upon examining Federal investments and interagency efforts, context is then provided in Section 5 around how both of these lines of work play into the U.S. STEM ecosystem at large. Finally, this analysis is used to fuel a discussion regarding the impact of the 2018 NSTC's STEM-Ed SP in Section 6.

Table 1 below provides a list of the acronyms used throughout this paper for easy reference.

3 The Federal STEM Education Ecosystem

The National Science and Technology Council (NSTC) is a United State's cabinet-level council for the executive branch established in 1993 by Executive Order.[9] The NSTC is responsible for coordinating science and technology policy across entities of Federal research and development (R&D). Within the NSTC, there are six primary committees and two special committees. Of the six primary committees, one is the Committee on STEM Education which is often referred to as CoSTEM.

CoSTEM was established in 2011 as called for by the America COMPETES Reauthorization Act of 2010.[10] The intent of this committee is to establish an interagency forum for discussion and

Table 1: Paper Acronyms

Abbreviation	Definition
AAAS	American Association for the Advancement of Science
CNCS	U.S. Corporation for National and Community Service (now AmeriCorps)
CoSTEM	Committee on STEM (within the NSTC)
DEI	Diversity, Equity, and Inclusion
DHS	U.S. Department of Homeland Security
DOC	U.S. Department of Commerce
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
DOL	U.S. Department of Labor
DOT	U.S. Department of Transportation
ED	U.S. Department of Education
EPA	U.S. Environmental Protection Agency
FC-STEM	Federal Coordination in STEM (within CoSTEM)
HHS	U.S. Department of Health and Human Services
IWG	Interagency Working Group
MSI	Minority Serving Institution
NASA	U.S. National Aeronautics and Space Administration
NIH	U.S. National Institutes of Health
NITRD	U.S. Networking and Information Technology R&D Program
NMSI	National Math and Science Initiative
NSF	U.S. National Science Foundation
NSTC	U.S. National Science and Technology Council
OMB	U.S. Office of Management and Budget
OPM	U.S. Office of Personnel Management
OSTP	U.S. Office of Science and Technology Policy
PIAAC	Program for the International Assessment of Adult Competencies
R&D	Research and Development
RFI	Request for Information
SBA	U.S. Small Business Administration
SI	Smithsonian Institution
STEM	Science, Technology, Engineering, and Mathemetics
STEM-Ed SP	NSTC's 2018 STEM Education Strategic Plan
USDA	U.S. Department of Agriculture
USPTO	U.S. Patent and Trademark Office
VA	U.S. Department of Veteran Affairs
WBL	Work Based Learning

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Federal STEM education policy coordination. As with every committee within the NSTC, CoSTEM is co-chaired by members of the Office of Science and Technology Policy (OSTP) in addition to leaders from Federal agencies such as the Nation Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA). In its charter, CoSTEM is given the responsibility for not only reviewing Federal agencies' STEM education programs, investments, and activities but also developing a plan for improvements.[11] Thus, the 2018 STEM Education Strategic Plan (STEM-Ed SP) was developed using extensive feedback from crucial STEM stakeholders.[12]

Within CoSTEM, there exists a subcommittee referred to as FC-STEM, which stands for the Federal Coordination in STEM Education. According to the charter of FC-STEM, the duties of FC-STEM include identifying and coordinating programmatic efforts to support priority goal implementations, developing models to optimize agency abilities to maximize the impact of Federal STEM education investments, and establishing evidence-based approaches to conducting STEM education research and evaluation.[13] Towards the first responsibility, the priority goal implementations mentioned specifically refers to the implementation of the goals outlined in the STEM-Ed SP. To fully maximize the impacts of Federal investments, progress needs to be transparent and iterative optimization must be utilized. For those reasons, FC-STEM provides formal progress reports detailing their review of the Strategic Plan's implementation annually. The progress reports on the STEM-Ed SP for 2019, 2020, 2021, and 2022 are publicly available and referenced in this paper, while the 2023 progress report remains yet to be published.[14,1,2,3]

Before looking at the data provided within the progress reports, it is important to describe the Strategic Plan itself. Within the 2018 STEM-Ed SP, four pathways were identified as providing great potential for leading our nation's Federal STEM education efforts towards it three goals. Those four pathways included

1. Develop and enrich strategic partnerships.
2. Engage students where disciplines converge.
3. Build computational literacy.
4. Operate with transparency and accountability.

The first three pathways listed focus on STEM pedagogy and are accordingly referred to as the 'educational pathways' within NSTC reports. The fourth pathway formalizes the Federal government's commitment to be open and evidence-based in their decisions surrounding STEM programs, investments, and activities. All four pathways consist of objectives that detail specific guidance and make clear the committee's priority actions when establishing effective STEM education. Fig. 1 shows these objectives and provides a top-level view of how all the pathways aim to contribute to the three goals within the plan.

Though the 2018 STEM-Ed SP has been well received within government, it is important to note that it is at its core a set of recommendations. Its products consist of best practice reports, guidelines, and advice. Any suggested actions relayed within these have yet to be mandated by law. For this reason, there is often data missing and inconsistencies in the progress reports when agencies experience challenges in reporting their programs, efforts, and investments. However, in

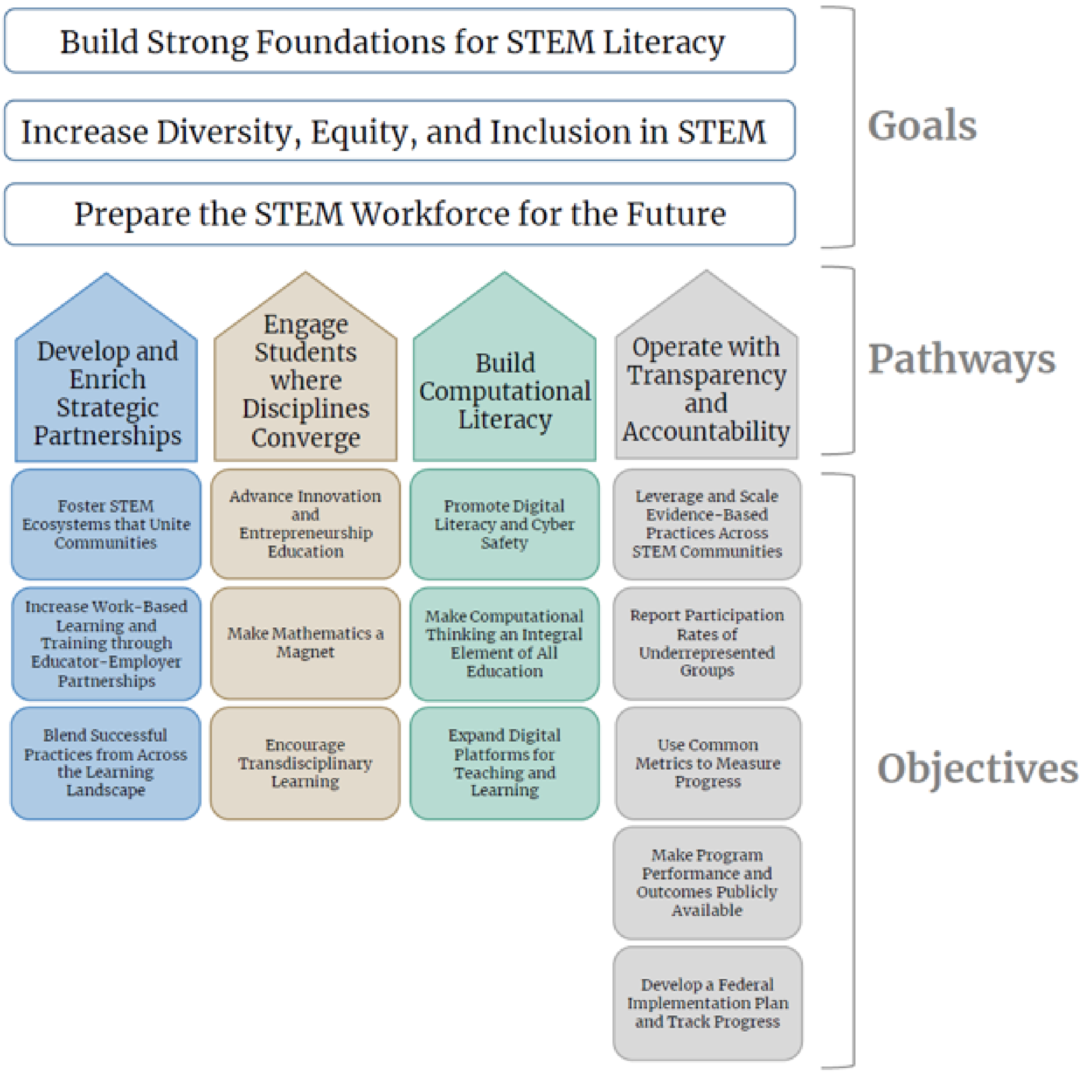

Figure 1: Schematic illustrating the organizational structure of the five-year STEM-Ed SP, developed by NSTC CoSTEM and released in December of 2018.[14]

terms of working toward the goals of the STEM-Ed SP, most agencies see the benefits of aligning with the NSTC STEM-Ed SP's recommendations since doing so can lead to further success for their STEM programs as well as greater justification for more support. This reality is important to keep in mind in reviewing such a plan's implementation progress as it scopes expectations and permits an appropriate amount of ambiguity.

When painting the picture for what the Federal STEM ecosystem looks like, the STEM Education Advisory Panel must be included. Established in October of 2017 under the American Innovation and Competitiveness Act, this 18 member-panel includes members from academic institutions, nonprofit organizations, and industry.[15] Members of the panel served up to three-year terms and met twice a year to collectively advice, provide information, and share concerns on STEM education R&D, training, implementation, interventions, professional development, and workforce needs. This panel provided a formalized route for non-Federal stakeholders to provide key insight into discussions of policy in the area of STEM education. This panel appears to have disbanded after their last meeting in the fall of 2022.

According to the meeting minutes from that final meeting in the fall of 2022[15], panel members departed after having shared insightful reflections, recommendations for the future, and encouragements for next steps. Within the reflections shared, it was mentioned that several panel members appreciated the opportunity to increase their understanding of how the Federal government works, thus demonstrating a desire for more active transparency when it comes to STEM education policy for non-Federal stakeholders of STEM education. Among the panel's recommendations provided, some that stood out were that Federal STEM efforts should

1. Ensure the inclusion of the multiple disciplines within STEM in future strategic plans and government programs.
2. Encourage the inclusion of STEM in reading and writing curricula.
3. Continue to establish and advocate for common definitions in STEM across agencies.
4. Continue to engage communities and leaders from the various sectors of STEM education.

Though the STEM Education Advisory Panel no longer meets, methods through which non-Federal knowledge regarding STEM education can be introduced into Federal initiatives and decisions needs to continue. The Advisory Committee for the Directorate for STEM Education (EDU) within NSF appears to do this, though its advice pertains primarily to NSF. Whether or not non-Federal advice should be introduced at the agency level or at an interagency level is important to evaluate in future STEM strategic planning. We suspect that for the most accurate and comprehensive information, the latter may be preferred as it eliminates additional links in the planning of wide-reaching initiatives.

Regardless, effective coordination across efforts within and outside of the Federal government must remain a priority in order to fuel a STEM ecosystem that allows for all three goals of the STEM-Ed SP to be best met. Alternatively, operating in silos as a nation in STEM education poses many problems. Whether those silos exist across specific STEM discipline or positions in the greater ecosystem, i.e. academia versus government vs public sector work, silos could lead to duplicative efforts, i.e. inefficient uses of money, persistent unmet workforce needs, and stifled innovation.

Overall, the landscape of Federal STEM education policy and initiatives during the tenure of the STEM-Ed SP appears to encourage STEM education efforts to be collaborative and expand beyond a single agency's or even the government's views alone. Such an approach is often referred to as a whole-of-nation approach. It is by working across the boundaries of the various Federal agencies and departments as well as the additional boundaries between government, academia, and industry that shared goals such as effective STEM education can be best achieved. The NSTC's 2018 STEM-Ed SP and the progress it has supported further demonstrate this claim. Fig. 2 provides a visual of the primary members of the Federal STEM Education ecosystem to further showcase how the products and guidance from NSTC's CoSTEM were outputs of a whole-of-nation approach.

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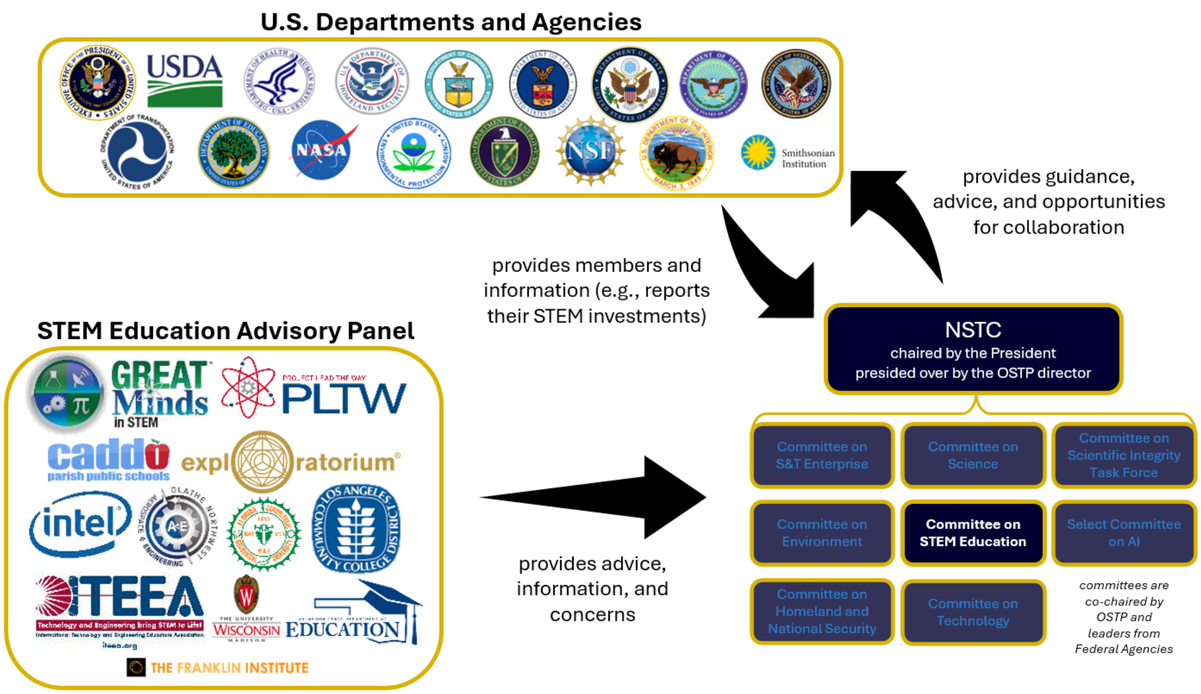

Figure 2: Illustration of the relationship of the NSTC, Federal agencies, and the STEM Education Advisory Panel.

4 The 2018 Strategic Plan's Implementation Progress

The implementation of the NSTC's 2018 STEM-Ed SP consisted of work conducted by interagency working groups (IWGs) as well as work done by individual Federal agencies. The nature of each of these categories of efforts remained distinct throughout the Strategic Plan's implementation. The IWGs focused on creating unity in STEM education and tools for a broad set of learners. Their work did not typically consist of developing individual programs that would provide STEM education to a particular set of learners, though they did often establish repositories and resources that such programs could use. On the other hand, agency-specific work often reached learners more directly, though these programs frequently did not utilize cross-agency collaboration.

4.1 The Interagency Working Groups' Accomplishments

In fiscal year 2019, CoSTEM stood up four IWGs to support work geared toward the goals and objectives of the NSTC's 2018 STEM-Ed SP. Each IWG was set up to focus on one of the Strategic Plan's four pathways. Additionally, a fifth and sixth IWG were established to focus on inclusion in STEM and supporting veterans in STEM careers in fulfillment of Section 308 of the American Innovation and Competitiveness Act and Section 3 of the Supporting Veterans in STEM Careers Act respectively.[2] These six IWGs and the agencies that are represented within them are listed in Table 3.

Throughout the last five years, much of what has been done by the various IWGs falls into the

Table 3: NSTC FC-STEM Interagency Working Groups (IWGs)

IWG Acronym	IWG Focus	Agencies
IWG-SP	Develop and Enrich Strategic Partnerships	DOC, DOD, DOE, DHS, DOI, ED, EPA, NASA, NSF, OSTP, and SI
IWG-C	Engage Students where Disciplines Converge	DOC, DOD, DOE, ED, NASA, NSF, OSTP, and SI
IWG-CL	Build Computational Literacy	DOC, DOD, ED, NITRD, NSF, OSTP, SI, and USDA
IWG-TA	Operate with Transparency and Accountability	DOC, DOD, DOE, ED, EPA, HHS, NASA, NSF, OMB, OSTP, and USDA
IWG-IS	Increase Diversity, Equity, and Inclusion in STEM	DOC, DOD, DOE, DHS, DOI, DOS, DOT, ED, EPA, HHS, NASA, NSF, OSTP, SI, and USDA
IWG-V	Support Veterans and Military Spouses in STEM	DOD, ED, EPA, NASA, NSF, OSTP, OMB, OPM, SBA, and VA

broad categories of establishing agreed upon definitions; creating guidelines; providing platforms and tools for collaborative problem solving, information sharing, and effort transparency; and establishing the STEM Investments Inventory.

4.1.1 Establishing a Common Lexicon

Prior to the 2018 STEM-Ed SP, policy makers, government agencies, educators, and learners would often use the same word to mean different things or different words to mean the same thing. To create a foundation for which work in STEM education could actually build off of, IWGs often needed to establish definitions for these enigmatic words. Some of the lexicon subsequently developed was specific to certain pathways and objectives while others proved central to the entire Strategic Plan's implementation.

For the IWG-C, one major effort was in formally defining convergence education. The resulting definition was provided in a 2022 report.[16]

Definition 4.1 (convergence education) *: education driven by compelling or complex socio-scientific problems or topics, where learners apply knowledge and skills using a blended approach across multiple disciplines to create and innovate new solution.*

This definition provides a common way to discuss practices that align with the cross disciplinary nature of many existing and emerging STEM fields.

Using responses from a 2020 FC-STEM Request for Information (RFI) and relevant research, the IWG-CL finalized its guiding definition of computational literacy in 2022.

Definition 4.2 (computational literacy) *: the ability to use information, information processing agents, digital assets, networking components, and applications and systems that, combined, allow people and organizations to interact in a digital world to solve problems, either individually or with a team; to draw meaning and reasonable conclusions from digital* *information in both personal and professional contexts; to safely, ethically, and securely use networks and data; and to understand how computing, data, and connectivity affects society.*

This definition was developed in hopes that it would provide a means to developing common metrics and clarity to enable accurate reporting of Federal agency actions regarding digital readiness.

More broadly, common terms for best practices proved requisite amongst all IWGs. At the beginning of the Strategic Plan's implementation, 'best practices' as a term was ubiquitous likely due to its use in a range of spaces such as education, research, business, industry, and public policy. Furthermore, IWGs needed a way to describe the various development stages that a given practice may be in so that entities could use recommended practices appropriately. This led to the development of shared definitions for evidence-based, emerging, and promising practices.

The definition for evidence-based practices was inspired by the National Institutes of Health's (NIH's) definition of evidence-based medicine.

Definition 4.3 (evidence-based practices) *: practices based on research and evaluation that have met some established test of validity.*

The Office of Personnel Management (OPM) and OSTP provided the definition for promising practices.

Definition 4.4 (promising practices) *: practices that are consistent with principles established by research but have not been verified by evaluation.*

Then, to allow for the incorporation of practices that have yet to be critically validated, emerging practices was defined.

Definition 4.5 (emerging practices) *: interventions that are new, innovative, or exploratory in nature.*

Though it did not result in a shared definition, the IWG-IS surveyed Federal agencies for their working definitions for 'underrepresented' in the context of groups of people within STEM. These results were presented in the IWG's report titled *Best Practices for Diversity and Inclusion in STEM Education and Research: A Guide by and for the Federal Government*.[17] In working towards the Strategic Plan's goal of increased diversity, equity, and inclusion (DEI) in STEM, agreeing upon what constitutes as an underrepresented population remains vital and has proven to be agency- and sometimes context-specific.

In addition to these definitions, each progress report on the STEM-Ed SP remained meticulous in defining STEM. Establishing a definition of STEM as a category of disciplines and outlining any intended nuances in the context of the STEM-Ed SP remained vital for both tracking work in STEM education and evaluating progress. For the purposes of the STEM Investments Inventory, a relatively narrow definition was chosen to allow the inventory to consist of programs of similar educational contexts.

Definition 4.6 (STEM) *: includes physical and natural sciences, technology, engineering, mathematics, and computer science disciplines, topics, or issues (including environmental science, environmental stewardship, and cybersecurity).*

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Recalling the STEM Education Advisory Panel's concluding recommendations, it is recognized that these definitions are only a starting point. As technology continues to advance and a more nationally unified approach to STEM education continues to be pursued, a greater amount of common definitions will need to be established. The adoption of these terms is also important and something that naturally takes time. Regardless, establishing this initial set of common definitions helps to minimize miscommunications and provide a clear articulation of what many of the key words within the pathways and objectives mean.

4.1.2 Generating Guidelines and Best Practices

Notable best practices compiled by the various IWGs included those focused on work-based learning (not publicly available), inclusive hiring and promoting DEI in the Federal STEM workforce[17], and how to promote computational literacy[18]. Though work-based learning (WBL) was a focus of the IWG-SP, one of the main takeaways from the roundtable events held regarding this topic was that WBL opportunities are a successful way to engage more students from underrepresented groups in STEM. In general, the progress reports demonstrate that it was not uncommon for IWGs to cooperate in establishing best practices and guidelines, especially when their findings led to insights relevant to another IWG's goal.

The IWGs' processes for establishing best practices often began with hosting roundtable events with majority agency representation as well as sending out surveys to gather knowledge of current agencies' standards and best practices. After varying methods of information assembly and validation, IWGs often published their findings to Federal entities. Then, webinars were held to disseminate the information to relevant stakeholders. Unfortunately, no formal documentation appears to be available providing insight into how often and to what degree these best practices and guidelines are currently being referenced by various agencies. Likely this is due to how new these resources are. Such documentation would be quite insightful in future efforts for quantifying the utility of much of the guiding work the FC-STEM IWGs completed.

An additional major output from the IWGs was the strategic plan to support veterans, service members, and military spouses in STEM education and careers. *The Strategic Plan to Improve Representation of Veterans and Military Spouses in STEM Careers* was published in December of 2021. It boasts four primary goals and an appendix of actions to be taken during the plan's implementation in order to achieve those goals. Under each action, agencies are assigned responsibility. Additionally, metrics are provided to allow for agencies to easily evaluate their progress towards completing the actions. From an outsider's perspective, having an outline of actions and perhaps most importantly, metrics, would have been beneficial in the 2018 NSTC's STEM-Ed SP. Such components could have allowed for a more accessible and complete understanding of the Federal STEM education ecosystem and its progress towards effective STEM education.

4.1.3 New Platforms and Tools

Some remaining key products developed by the IWGs include the NSF INCLUDES Initiative and the NITRD STEM Portal. The NSF INCLUDES Initiative, though housed by NSF, remained a key area of focus for the IWG-SP throughout the 2018 STEM-Ed SP's implementation. This program promotes the formation of new partnerships and research that help address STEM-inclusion challenges at a national scale. At its core, NSF INCLUDES is a grant-providing initiative that funds pilot programs in STEM education to broaden participation and build a higher capacity for collaborations such that they could one day become future STEM centers, alliances, or other large-scale networks. In 2018 and 2019, eight different alliances were funded. By 2022, NSF INCLUDES expanded to fund eleven different partnerships and networks.[19]

Where NSF INCLUDES focuses on financial support, the NITRD STEM Portal aims to provide access. The NITRD STEM Portal is a searchable database for agency-sponsored internships, training programs, apprenticeships, fellowships, and other programs.[20] It was populated in fiscal year 2022 with the help of the IWG-CL.[3] Because the NITRD STEM portal's goal is to best allow students and educators to easily obtain information on the numerous opportunities available to them and their students, the contents of the database expands beyond what the STEM Investments Inventory encompasses. The STEM investments inventory, for instance, does not include post-doctoral fellowships, broad education programs not specific to STEM, ad hoc opportunities, and outreach efforts focused on the education about an agency and its activities.

According to the available progress reports, it appears that there may additionally be a few other platforms still in development. The IWG-TA, for instance, shared in the 2022 progress report that they have began assembling material for a toolkit of resources on metrics commonly used in STEM education programs.[3] In the same progress report, there is mention of the IWG-CL's work in identifying types of digital platforms and tools used to deliver computational literacy education and training efforts. It has yet to be seen whether these and other outputs that have been alluded to will be published in a 2023 progress report or otherwise shelved or delayed.

4.1.4 Establishing the STEM Investments Inventory

The creation of the STEM Investments Inventory is arguably one of the most important efforts of the IWG-TA. Early on in the Strategic Plan's implementation, the IWG-TA recognized that there was a lack of common reporting methods available to begin tracking progress towards the STEM-Ed SP's goals. For that reason, they established the STEM Investments Inventory in 2018. In reporting a STEM investment an agency provides CoSTEM with the program or effort name, what agencies are affiliated with it, the monetary investment associated with it, and its relevance to the Strategic Plan's goals and pathways. To be considered an investment, the funded STEM education activity must have a dedicated fiscal year budget of at least $\$300,000$ and staff assigned to manage its budget.

Interestingly, it was not until 2021 that the IWG-TA established a set of guidelines for defining 'participants' and what constitutes a rural area. Once it had, these became additional inputs for agencies when submitting investments to the inventory. Consequently, it was not until the 2022 progress report that any amount of participant information was included in the inventory. Likely due to its novelty, twelve out of the seventeen 2022-reporting government entities did not provide any participant information. Thus, as it stands, tracking progress in DEI is difficult for at least 71% of the participating Federal entities. For a data-driven evaluation, future years' inventories will need to be gathered and analyzed.

In the following section, Section 4.2, we share our data-focused evaluation of the progress revealed from the STEM Investments Inventory in greater detail.

4.2 Individual Agency Efforts

The aforementioned STEM Investments Inventory is the primary repository of individual Federal agencies' STEM education efforts. It is intended to quantify and qualify the bulk rather than the absolute total of Federal STEM investments and programs. By setting criteria, such as the investment amount minimum, agencies must only work to gain accurate reporting information for their largest and hopefully most impactful efforts. It is through this self-reporting that agencies identify the goals and pathways of the Strategic Plan that their efforts support as well as how much they invested toward each effort and what organizations and populations their efforts serve.

GOALS FOR AMERICAN STEM EDUCATION

★ Build Strong Foundations for STEM Literacy ★

★ Increase Diversity, Equity, and Inclusion in STEM ★

★ Prepare the STEM Workforce for the Future ★

Pathways	Objectives	DOC	DoD	DOE	DHS	DOI	DOL	DOS	DOT	ED	EPA	HHS	NASA	NSF	SI	USDA
Develop and Enrich Strategic Partnerships	Foster STEM Ecosystems that Unite Communities	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Increase Work-Based Learning and Training through Educator-Employer Partnerships	●	●	●	●	●	●			●	●	●	●	●	●	●
	Blend Successful Practices from Across the Learning Landscape	●	●	●	●		●	●		●	●			●	●	●
Engage Students where Disciplines Converge	Advance Innovation and Entrepreneurship Education	●	●	●				●		●	●	●		●		●
	Make Mathematics a Magnet	●	●							●				●		●
	Encourage Transdisciplinary Learning	●	●	●	●	●		●		●	●	●	●	●	●	●
Build Computational Literacy	Promote Digital Literacy and Cyber Safety	●	●		●			●		●		●		●		●
	Make Computational Thinking An Integral Element of All Education	●	●	●	●	●				●		●		●	●	●
	Expand Digital Platforms for Teaching and Learning	●		●	●			●		●				●	●	●

Figure 3: The educational pathways and objectives under the STEM-Ed SP and which Federal entities planned to contribute to each through mission-specific actions.[12]

At the onset of the STEM-Ed SP in 2018, ten out of the fifteen original FC-STEM agencies (67%) declared that their goal was to contribute to at least six of the nine objectives, while eleven of these same agencies (73%) desired to directly contribute to all three goals. This can be seen in Fig. 3, which was pulled from the 2018 STEM-Ed SP. In the 2022 publicly-available STEM Investments Inventory, however, 140 out of the total 162 investments (86%) that were listed in Appendix 6 claimed every goal as a direct or indirect outcome. In the absence of a more refined analysis, this sounds like great progress has been made in STEM education as it suggests the majority of investments are contributing to all of the STEM-Ed SP's goals. Unfortunately, only 8 of the 162 investments detailed in the 2022 STEM Investments Inventory (5%) have publicly available evaluations, thus making it difficult to verify what it means for these programs to have direct or indirect impact on a particular goal.

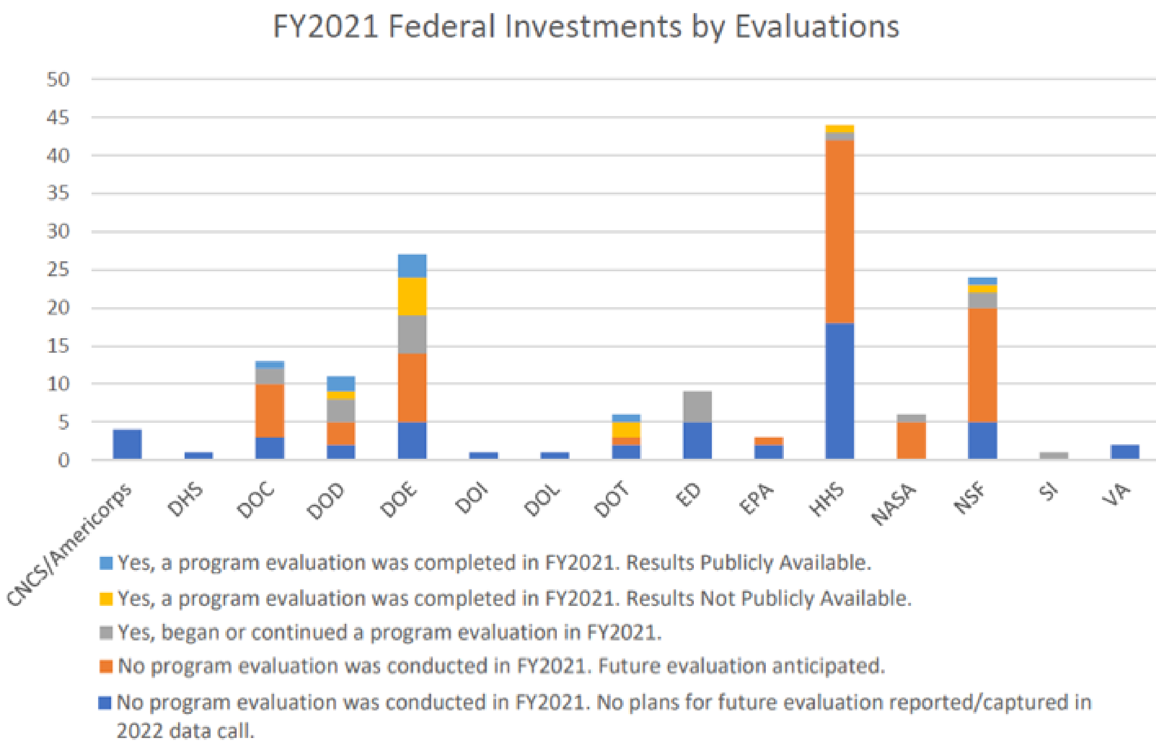


Figure 4: A graph of each FC-STEM agencies' investments and their status of programmatic evaluation.[3]

Because reporting guidelines are new and not yet used consistently from agency to agency, these sorts of observations are not entirely unexpected. It is recognized that the data in the inventory is derived from agencies voluntarily responding to requests for data. Though agencies may try their best to be accurate, it is important to acknowledge that there exist barriers in reporting accurately. To name a few, barriers include the time and cost of achieving accurate reporting, inherit difficulties in identifying participants such as when the effort is hosted online, the very recent arrival of a definition for a rural area, and confusion surrounding what qualifies as a sufficient duration of participation.

Despite the multitude of barriers, the 2022 progress report on the implementation of the STEM-Ed SP states that over 60% of investments had some type of associated evaluation. This could include a formal evaluation, whether it be publicly released or not, as well as focus groups and surveys. When asked about the future, many of the remaining 40% of investments indicated they anticipate conducting an evaluation in the coming years, as seen in gray and orange in Fig. 4.[3] For the time being, however, both the limited amounts of completed evaluations and publicly-available information continue to make detailed aggregated analysis of progress difficult.

To understand the inspirational affects of the Strategic Plan, we tracked the development of new programs in the inventory from 2018 to 2021. As seen in Table 4, on average, the percentage of funding going toward new programs was approximately 6%. This 6% should be considered an upper bound as sometimes an agency's reporting style for a particular program changed over the full four-year span causing an existing program to be renamed and scoped differently. In those cases, the existing program often appears to be discontinued and a new program simultaneously appears to come into existence even though the two efforts may be related. Moreover, the 2022 progress report admits that "most Federal investments were created before the creation of the 2018 Federal STEM Education Strategic Plan".

Table 4: Funding for New STEM Investments by Fiscal Year

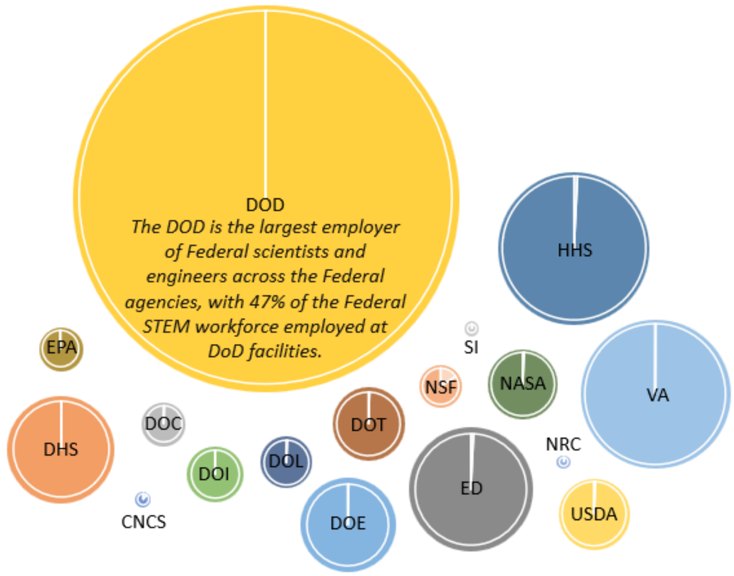
	FY19	FY20	FY21
Number New Programs in FY	54	24	26
Funding for FY New Programs [$,million]	292.6	153.1	213.6
% of Funding for FY New Programs	8.25%	4.37%	5.34%
Total Funding for FY [$,million]	3540.5	3503.6	4003.6

Of the new efforts reported, very few appeared to be multi-agency efforts. However, many had strategic industry or non-profit partners. For instance, The Department of Commerce's (DOC) United States Patent and Trademark Office (USPTO) launched its first virtual Noche de Ciencias (Night of Science) in collaboration with the Alexandria City Public School system in Virginia and the Society of Hispanic Professional Engineers (SHPE). Though this event has not yet become monetarily large enough to qualify for the STEM Investments Inventory, Noche de Ciencias serves as a prime example of strategic partners being utilized for programs that are developed to serve a particular underrepresented population in STEM. The general trend of collaboration, though not with another Federal agency, suggests that programs were likely developed to focus on a single agency's mission. A natural follow-up question then became, which missions are primarily supported in the efforts represented within the STEM Investments Inventory?

Fig. 5 shows both a table and graphic describing the FC-STEM agencies' discretionary funding in fiscal year 2021 in comparison to the amount they invested in STEM education according to their reported efforts. In the bubble chart, the white slice for each agency represents their spending on the STEM education efforts they have listed in the inventory. Though the U.S. Department of Defense (DOD) has the largest discretionary funding and employs 47% of the Federal STEM workforce[3], we found that it ranked fourteenth in percentage of its discretionary funding being put towards STEM education. In terms of absolute amounts however, the DOD does spend the fourth most on STEM education.

Top ranking agencies, both in total amount and percentage of their discretionary budget going to STEM education are the NSF, ED, and the U.S. Department of Health and Human Services

Entity	Discretionary Funding, FY21 ($, millions)	STEM Funding, FY21 ($, millions)	Percentage of STEM Funding, FY21 (%)
NSF	8500.00	1354.31	15.93
CNCS	1121.00	123.10	10.98
NRC	863.00	19.40	2.25
ED	73000.00	566.50	0.78
HHS	108600.00	838.90	0.77
NASA	23300.00	157.50	0.68
USDA	24400.00	164.30	0.67
DOL	12500.00	74.00	0.59
DOT	25300.00	149.30	0.59
SI	1033.00	5.70	0.55
DOC	8900.00	44.60	0.50
DOE	41900.00	172.30	0.41
VA	104500.00	77.10	0.07
DOD	703700.00	245.00	0.03
EPA	9200.00	2.90	0.03
DHS	53800.00	7.80	0.01
DOI	14900.00	0.90	0.01



STEM Year in Review FY 2019 (dodstem.us)

Figure 5: A bubble chart representing each Federal agency or department's full discretionary budget with a slice for how much is being used for STEM education investments.

(HHS). When considering these agencies' missions, which are to promote the progress of science, promote student achievement and preparation, and enhance the health and well-being of all Americans respectively, it becomes clearer that STEM education may be naturally a higher priority for these agencies as opposed to other agencies. It is this priority that we believe is reflected in Fig. 5.

In total, Fig. 6 shows that the amount of Federal spending being put toward STEM education initiatives and programs rose from approximately three billion to four billion from fiscal year 2018 to 2021. Fig. 6 also shows how agencies like the the U.S. Department of Agriculture (USDA) and the U.S. Department of Energy (DOE) appear to have increased in their share of the total agency investments in STEM education over that same time frame. Also revealed from this visualization is how highly-invested agencies tend to have a handful of highly invested programs and then multiple smaller efforts. Because most STEM investments are funded via multiple appropriations from Congress, this graphic demonstrates that the approximately one billion dollar increase in Federal STEM education funding is being utilized by multiple entities and not necessarily just the few whose missions more closely overlap with achieving effective STEM education.

Top funded programs listed in the inventory can be seen in Table 5. Of these ten investments, which encompass nearly 39% of fiscal year 2021's STEM education investments, none are new. Towards determining the progress of the Strategic Plan's three goals, it can then be useful to map these top funded initiatives to which of the goals their respective agencies identified as being directly contributed to through their programs. In Table 5, the column labeled 'Goal(s)' provides this mapping; the goal of STEM literacy for all is identified via an 'L', DEI in STEM is a 'D',and STEM workforce preparedness is a 'W'.

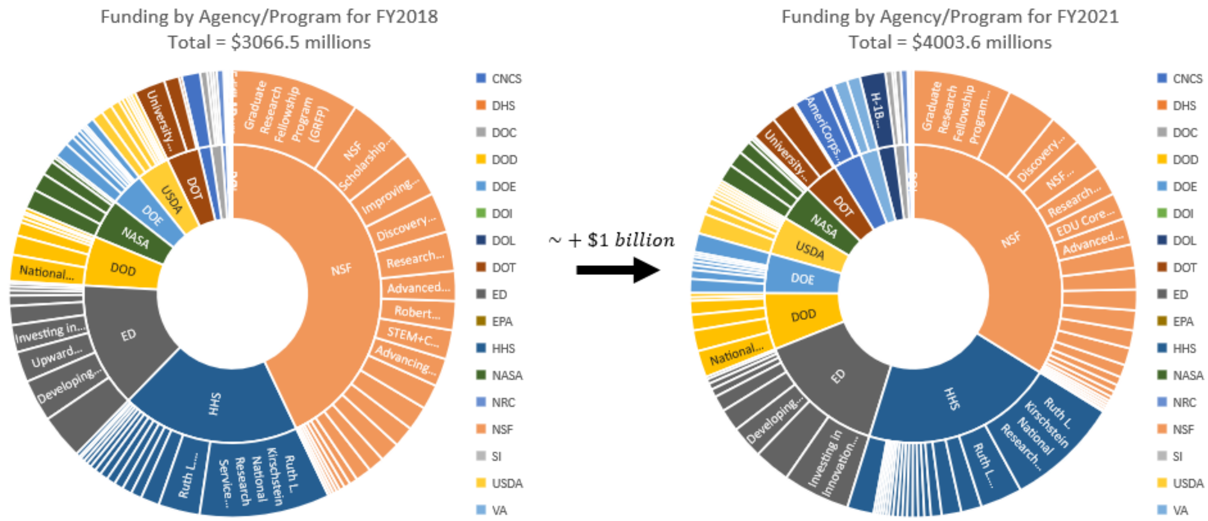


Figure 6: Funding trends shown in the STEM Investments Inventory from FY18 to FY22. Slices are proportional to the amount of funding for a given fiscal year.

Table 5 reveals that 60%, 70%, and 80% of these top ten investments identify STEM literacy, DEI, and workforce preparedness respectively as a goal they directly support. When expanding to look at the top twenty funded programs, these numbers become 50%, 60%, and 70%, as there are five out of those twenty programs for which none of the three Strategic Plan's goals are being directly contributed to. It should be noted that this does not include designations of a program's indirect contributions. Regardless, this portrays two key points. First, the goals appear to be prioritized by agencies in the order of preparing the STEM workforce, improving DEI in STEM, and then ensuring STEM literacy for all. Second, the Strategic Plan's goals appear to have little influence on at least a fourth of the highly funded programs as they have not claimed direct impact in any of the goals of the plan.

Despite some programs appearing to remain less impacted by the pathways and goals of the STEM-Ed SP, we recognize that the annual progress reports contain ample examples of the opposite case. In the descriptive contribution sections of the progress reports, it is evident that agencies have become more mindful to the goals and pathways within the STEM-Ed SP. An example of this is the U.S. Department of Energy's (DOE) documented interest in identifying barriers to participation in DOE programs and opportunities. In 2021, they hosted over a dozen sessions with students, faculty, and administrators from minority serving institutions (MSIs) to help identify the barriers that exist. Then in February of 2022, they launched a program called Reaching a New Energy Sciences Workforce (RENEW). RENEW aims to support projects at MSIs and non-R1 institutions of higher education to develop the capacity to train undergraduates and graduate students in STEM fields.

Though only one example was provided here, many of the FC-STEM agencies provide similar testaments when describing the changes they have made to existing efforts as well how their new STEM education programs came to fruition. It remains evident, however, that there is a lack of metrics at the top level for evaluating the progress made by both IWGs and the individual Federal

Table 5: Top Funded STEM Education Investments

Agency	Program Name	FY18	FY19	FY20	FY21	Goal(s)
HHS	R. L. Kirschstein NRSA - Institutions	288.8	303.4	313.4	328.5	W
NSF	Graduate Research Fellowship Program	284.9	284.5	284.5	284.5	DW
ED	Education Innovation and Research	60.0	78.0	65.0	194.0	LD
NSF	Improving Undergrad. STEM Education	99.1	101.9	109.5	145.7	LDW
HHS	R. L. Kirschstein NRSA - Predoc. Fellows	91.7	100.2	110.9	121.2	DW
ED	Teacher Loan Forgiveness	99.1	105.4	100.0	105.0	
NSF	Discovery Research K-12	88.6	88.2	95.0	95.0	L W
NSF	NSF Scholarships in STEM	156.4	114.8	79.9	94.7	LDW
ED	Developing Hispanic Serving Inst. STEM	93.4	93.8	94.1	94.3	LDW
CNCS	AmeriCorps State and Nat. Competitions	41.0	70.5	66.7	90.5	LDW

agencies throughout the implementation of the 2018 STEM-Ed SP. Additionally, there exist minimal transparency in the Federal documentation on what gaps still remain or have been filled thanks to the work conducted in response to the STEM-Ed SP. At the national level, we could alternatively look to the Global Innovation Index's percentage of STEM degrees or the PIAAC's digital literacy metrics for an indication of progress, but the interpretation of these metrics will still leave room for nuances as to how the 2018 Strategic Plan truly played into any perceived progress.

5 Context within the Greater STEM Ecosystem

Though much of the work presented in both this paper and the Strategic Plan's progress reports was led and carried out by government agencies, the truth is that the STEM-Ed SP was designed to serve as a 'North Star' for the broader STEM community. This is why it is titled *Charting a Course for Success: America's Strategy for STEM Education* and features a large, bright star on its cover page.[12] Beyond guiding Federal activities and investments, it was intended to allow the full U.S. STEM ecosystem to begin aligning their goals and establishing best practices. This was evident through the formation of the IWG-SP and the STEM Education Advisory Panel. Since the NSTC is a council of advisers for the government, it comes as no surprise that strengthening the Federal commitment to components of the STEM-Ed SP has became the foremost focus in its implementation. Establishing buy-in and creating incentives for participation of non-government stakeholders remains secondary.

Despite the desire of adoption by the greater U.S. STEM ecosystem, five years since the introduction of the STEM Education Strategic Plan, it remains evident that the progress being documented remains government-focused. With an ecosystem consisting of non-profit organizations that regularly get young students interested in STEM degrees and careers like Project Lead the Way (PLTW), a pre-engineering set of curricula for high school students; FIRST Robotics, a nation-wide enrichment competition getting K-12 students in robotics; and museums not limited to the Smithsonian Museums that showcase STEM breakthroughs and innovations to many, there remains much more to be built upon. In support of increasing DEI in STEM and building STEM literacy for all, we believe that great strides could be made if insight was drawn from and collaborations were made with organizations like the National Math and Science Initiative (NMSI) in addition to PLTW, FIRST, and others.

NMSI in particular is a nonprofit organization whose mission is to advance STEM education and ensure all students, especially those furthest from opportunity, thrive and reach their highest potential as problem solvers and lifelong learners.[21] They have collections of relevant research, run educational programs, and provide a wide array of resources that could be of great use to a whole-of-nation STEM education initiative. One resource of special interest is the STEM Opportunity Index, a multi-layered map that shows how states, school districts, and individual schools are performing in ten conditions, practices, and outcomes that experts believe are critical to identifying where STEM education is being successfully delivered. Considering the goals of the STEM-Ed SP under the constraints of the multiple geographical contexts that exist within the U.S., like the STEM Opportunity Index allows for, could prove particularly useful.

Looking back within the government, there also exist other means by which STEM programs are funded aside from the agency appropriations that are conventionally used to fund the programs listed in the STEM Investments Inventory. One source we can look to are the thousands of earmarks made in 2022 by House members. Among these earmarks, the American Association for the Advancement of Science (AAAS) identified hundreds of projects relevant to STEM.[22] These earmarks funded a range of programs from those focused on K-12 STEM education to the creation of new research institutions and technology parks. Not only would looking at these programs in conjunction with the efforts made by IWGs and individual agencies perhaps provide a fuller picture of government spending on STEM education, but it could also lead to the identification of synergies between the two types of efforts.

At a state level, our research also revealed that the states of Washington and Massachusetts have enacted STEM legislation that have led to reports and data collections that could be useful to a nation-wide effort. Washington state's governor passed the bill, E2SHB 1872, in 2013.[23] Under this bill the STEM Education Innovation Alliance was established and subsequent annual STEM report cards and a dashboard were created in the following years. Similarly, Massachusetts's General Law Chapter 6, Section 218 created the Commonwealth's STEM Advisory Council, which provides annual report cards and a dashboard as well. This advisory council also authored two versions of a *Plan for Excellence in STEM Education* which highlight goals like increasing student interest in STEM and increasing the number of skilled STEM educators.[24,25] The continued and clearly articulated goals for STEM education in the commonwealth is likely one of many reasons that Massachusetts remains among the top states in K-12 mathematics and science testing performance.[26]

Looking back to Federal initiatives, these plans, reports, and dashboards exemplified at the state level could provide key insight into gaps that need to be addressed in STEM education. Such gaps could be defined by which populations are being overlooked, which geographic areas are underserved, at what points in the STEM pipeline undesired challenges exist, and what areas of STEM are being inadequately supported. Knowledge of these gaps could greatly aid future STEM education strategic plans and efforts. From the whole-of-nation perspective, however, if only a subset of states are collecting the necessary data to provide such insight, the full picture of STEM education needs will remain unclear.

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6 Conclusion

The progress detailed in the NSTC's 2018 STEM Education Strategic Plan (STEM-Ed SP)'s progress reports suggest growth in the plan's three goals of preparing the future STEM workforce, improving DEI in STEM, and building strong foundations for STEM literacy. However, this progress is not perfectly evident in the data currently available. Unfortunately, no metrics were established at the STEM-Ed SP's conception to directly allow stakeholders to understand what progress has been made. In describing the Federal STEM ecosystem, evaluating the progress defined in reports, and conducting our own data analysis of the STEM Investments Inventory, we have summarized the progress evident as well as identified some shortcomings and provided suggestions for future STEM education initiatives.

Primary areas of suggested future work include defining what qualifies as success via metrics that make progress more transparent to the public, building a stronger connection with key non-Federal STEM stakeholders when aiming for a whole-of-nation engagement, and continuing much of the work already initiated. It is anticipated that the STEM Investments Inventory will become more accurate as agencies grow more familiar with reporting expectations and learn how to overcome reporting obstacles. We also anticipate that identifying gaps in effective STEM education will become easier as this data evolves to paint a fuller, more complete picture of where time, money, and effort is being placed in STEM education in the Federal government. However, if work in defining and actively implementing Federal STEM education goals dwindles with the conclusion of the NSTC's 2018 STEM-Ed SP, we suspect key insights will be lost if evaluations remain reliant on incomplete or out-of-date data and progress continues to remain ambiguous.

To avoid putting the pressure of efficient STEM education purely on the continuance of an NSTC STEM-Ed SP, it may also be worthwhile to consider the need for an education Federally Funded Research and Development Center (FFRDC). Whether it is an FFRDC or some other similar third-party entity, the findings of this paper suggest that establishing such an entity to serve as the bridge between government and the public and private sectors to carry out programs, research studies, and other efforts focused on effective education may be greatly beneficial at this point in time. Many FFRDCs directly support work centered around a national need such as health, cybersecurity, and national security. As the demand for an innovative and technically capable Federal workforce is becoming harder and harder to meet, especially in the wake of international competition in areas of innovation, such considerations should be evaluated sooner rather than later.

Finally, another potential consequence of inconsistent Federal strategy is that members of the greater STEM ecosystem could become hesitant to align with the Federal government's goals and pathways as it could be seen as precarious. All things considered, the implementation of the 2018 STEM-Ed SP should serve as a great first step in a series of nation-wide efforts to improve STEM education so that the U.S. can remain innovative and competitive in an ever-increasingly, technology-driven world.

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