Accelerating Progress in U.S. Education: Key Lessons From Other Federal R&D Investments in Technology and Innovation

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Introduction

In his February 2, 2023 blog post, Institute of Education Sciences (IES) Director Mark Schneider described his vision for a major reimagining of the federal role in education research that would emphasize innovation and technological advances. Writing that "in the heart of every federal agency lies a dream of becoming the next DARPA," Schneider (2023, para. 1) described the potential benefits of an organization within the U.S. Department of Education that would adopt some of the features of the Defense Advanced Research Projects Agency (DARPA) and similar research and development (R&D)-focused agencies such as the Advanced Research Projects Agency-Energy (ARPA-E) in the Department of Energy and the Advanced Research Projects Agency for Health in the Department of Health and Human Services. The proposed New Essential Education Discoveries Act[1] would support the development of a similar organization in the Department of Education. This National Center for Advanced Development in Education (NCADE) would have responsibility for "developing and scaling innovative, cutting-edge practices and tools modeled on the strategies that have been so successful at DARPA" (Schneider, 2023, para. 5).

Features of NCADE from Schneider (2023)

- Research driven by important use cases about important issues for which there is currently no clear solution path
- A high-risk/high-return model in which failure is accepted and viewed as a source of learning
- Faster, more efficient, and more cost-effective approaches that prioritize continuous improvement
- An emphasis on advances in education technology and data science methods
- New approaches to program management

There has been no shortage of advice[2] regarding how IES might reinvent itself to improve the utility, relevance, and impact of the research it funds.[3] Nor is there a lack of efforts to glean

[1] https://bonamici.house.gov/media/press-releases/bonamici-fitzpatrick-introduce-bipartisan-bill-spark-innovation-education
[2] https://nap.nationalacademies.org/catalog/26428/the-future-of-education-research-at-ies-advancing-an-equity; https://drive.google.com/file/d/1XbA8G8p9u52fLvKVM78K3UBNevbUbNkn/view
[3] See for example H.R. 8548 from the 117th Congress.

lessons from DARPA, some of which we reference below. This brief complements this other work by (a) reviewing what scholars and policymakers have learned about DARPA and other agencies modeled on it, and (b) applying that learning to education research and its contexts, with the goal of informing the design and implementation of NCADE. In the next section, we provide a brief overview of key features of DARPA and ARPA-E. We then summarize some key themes from our reviews of materials related to DARPA and ARPA-E,[4] discussing their implications for NCADE and other innovation-oriented education research agencies. This discussion of implications can inform the work of IES and the other federal agencies with which IES collaborates. We conclude the report with some questions that remain open and that will need to be considered as NCADE is designed and implemented. Although our primary audience is the set of federal agencies that support education research, this brief could be of interest to the broader community of education policymakers, practitioners, and researchers as they work together to envision new models of education R&D.

APPROACH AND LIMITATIONS OF OUR ANALYSIS

To identify implications and recommendations that can inform the design of NCADE, we undertook a rapid information-gathering effort that included reviewing DARPA and ARPA-E websites, selected related literature (see reference list at the end of this document), and the Congressional Record.[5] Because of the limited scope of our work, we caution readers to interpret our findings and implications within the broader literature about the future of education research. In particular, we do not cover the wide and growing body of work on innovation in education research. Moreover, our understanding of these federal R&D agencies is limited due to the narrow set of activities we conducted, which did not include interviews with agency leaders or other approaches that could have provided a more-detailed picture of these agencies' activities and accomplishments. Nonetheless, we believe that our effort to investigate the major successes and challenges of these federal R&D-focused agencies through the lens of education research provides useful guidance that complements other sources of input to IES.

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[4] We limit our discussion to DARPA and ARPA-E because the other agencies modeled after DARPA are either in development or too new to have generated significant lessons.

[5] Two AIR colleagues who have been in frequent contact with DARPA, who are not listed as authors, provided context for our review.

DARPA and ARPA-E: A Brief Overview of Key Features and Accomplishments

DARPA's origins and history have been the subject of a variety of analyses over the agency's lifespan, and we draw on a few of these for this brief (see references list). Here, we do not attempt a comprehensive treatment but instead provide some key information to help readers interpret the discussion of findings and implications that follows.

The Advanced Research Projects Agency (ARPA) was created in early February 1958. Today, the agency is called DARPA. The "D" was added in 1972 to signal an emphasis on defense. DARPA currently has an enacted budget of $3.9 billion. DARPA's 220 employees are spread across six technical areas (Biological Technologies, Defense Sciences, Information Innovation, Microsystems Technology, Strategic Technology, and Tactical Technologies). Approximately half of DARPA's employees are short term (with an average tenure of 4 years) program managers doing work across 250 R&D programs. DARPA funding represents approximately 25% of the Department of Defense's (DoD's) total science and technology funding, and 2% of all federal research and development funding. The R&D programs fund approximately 2,000 contracts, grants, and other agreements with companies (67% of funding), universities (17% of funding), DoD, and other labs.[6] While many advances in the early days focused on missile and ballistics technology, DARPA's current set of six technical areas represents an expansion of what it means to deter and defend against highly capable adversaries in a host of situations.

ARPA-E is a much newer agency that has not yet generated the vast amount of analysis and literature that DARPA has.[7] Its origin can be traced to a 2005 request from Congress for the National Academies of Sciences, Engineering, and Medicine (National Academies) to "identify the most urgent challenges the U.S. faces in maintaining leadership in key areas of science and technology" and to provide recommendations to help ensure the nation's competitiveness, security, and prosperity. Informed by the National Academies' report, then-president Bush signed the America COMPETES Act in 2007, authorizing the creation of ARPA-E. The agency launched in 2009 with the purpose of funding R&D that would generate advanced energy technologies.

[6] This information is drawn from DARPA's website (Defense Advanced Research Projects Agency, n.d.).
[7] This information is drawn from ARPA-E's website (Advanced Research Projects Agency-Energy, n.d.).

Several features of ARPA-E were modeled after DARPA, including its mission to fund "high-risk, high-reward" applied R&D; an emphasis on speed at all stages of the project lifecycle, from funding decisions to market application; and an emphasis on innovations that might not be ready for private-sector investment. Its approaches to management and organizational structure also resemble DARPA's, with a reliance on short-term leadership positions filled by staff with a mix of academic, government, and industry experience. Program directors seek proposals for work on specific topics, but the agency also occasionally solicits work that falls outside of a specific program area. Its annual budget has ranged between $180 million in 2011 and $427 million in 2021, with a requested budget in 2022 of $500 million. Since 2009, it has provided roughly $3.3 billion to a mix of universities, small and large businesses, National Laboratories, and nonprofits. Its work has led to the formation of 131 companies and 934 patents, and it has resulted in significant advances in areas such as better batteries, more-efficient wind turbines, and new approaches to carbon capture and storage.

DARPA and ARPA-E Analysis: Key Findings and Implications for NCADE

Readers who are familiar with the education R&D sector will recognize that lessons regarding the work of the two agencies discussed in the previous section are not necessarily directly applicable to the education context. At the same time, in light of the desire to replicate features of these agencies to advance innovation in education, it is helpful to consider potential implications before launching a new, ARPA-like agency in the Department of Education. In this section, we distill our major findings from our DARPA and ARPA-E explorations and describe corresponding implications for NCADE. We highlight themes that may be especially important and that have largely not been addressed in other writings about applications of the DARPA model to education R&D. Because of DARPA's long history and the extensive body of work examining it, the discussion focuses mainly on DARPA, but we bring in findings related to ARPA-E where relevant.

Agencies’ design should be informed by a clear sense of purpose.

DARPA was driven by a well-articulated sense of purpose and a small number of key objectives.

The role of the Sputnik launch in the creation of DARPA is well known. Analyses suggest that a desire to avoid being caught off guard again by a Sputnik-like surprise and instead to ensure that the United States would be the creator of future surprises provided a key rationale for DARPA and informed its creation. As Bonvillian (2018) noted, “DARPA became a unique entity, aimed at both avoiding and creating ‘technology surprise’” (p. 897). This commitment to being the originator of new technologies resulted in a military-focused R&D effort whose main goal was to get ahead and stay ahead of the Soviet Union, primarily through innovations in defense technology. Vigorous opposition to the growing influence and potential advancement of communism made choices about what to support relatively easy in the beginning. As it became evident over time that machines were not the sole answer to maintaining a military lead, innovations related to people (e.g., rapid disease detection and mitigation, efficient nutrition in adverse situations, non-narcotic pain management, mental and physical wellness beyond physical endurance) began to emerge in the mix of ideas taken up by DARPA. The shifting context over the decades saw ARPA become DARPA, with the “D” added to signal a focus on “defense.”[8] Many projects retain an offensive posture, though they are couched in defensive terms, guided by a desire to avoid political destabilization (e.g., thermonuclear and bioweapons) while simultaneously projecting military preeminence.

Implications for NCADE: A clear articulation of the purpose of NCADE, and of the U.S. education system more generally, should guide the planning and execution of this new center. DARPA launched with a relatively clear purpose—to ensure the country’s scientific and technological dominance over its global adversaries.

Although global economic competitiveness plays a role in many policy debates about U.S. schools, it is far from the only concern. Public debates about the purposes of schooling have changed over time, often in ways that reflect high-profile events. Education can benefit individuals as well as communities and societies, and it can provide services that range from instruction in core academic subjects to supports for mental and physical health. Schools are expected to produce well-rounded workers and citizens, but educators often lack clear guidance about how these outcomes should be defined and measured, and about what kinds

[8] The shift to signaling a more overt focus on defense, rather than offense, was one result of Congressional criticism of ARPA’s Vietnam-era exploits. This shift left many in Congress uncomfortable with the fruits of ARPA’s mission.

of activities they should prioritize to achieve those outcomes. Further, there is often a lack of agreement about how to prioritize resources across students with varying needs and interests, such as students with disabilities, English learners, and students who demonstrate advanced levels of performance. This lack of clarity regarding the purposes of education influences the work of schools and affects how research is designed and funded.

To achieve its intended impact, NCADE must be designed in a way that reflects to the extent possible, agreement about (a) what we want schools to accomplish and for whom, and (b) the primary objectives of NCADE that align with these goals for public education. If the main objective of education were defined as promoting economic competitiveness by ensuring that U.S. students outperform their peers in other nations on academic achievement tests in core subjects, the R&D agenda would need to be designed to advance this objective. The resulting research agenda would look somewhat different from one that prioritized another objective, such as creating schools that promote whole-child development or that prioritize equity of learning opportunities across the full curriculum. Moreover, NCADE's work should be informed by ongoing evaluation of the needs of learners and educators, with core objectives modified in response to changing conditions and priorities.

Consider how people and their values will influence the agency's priorities and work.

The expansion of DARPA's scope to incorporate innovations focused on people reflects, in part, the shifting interests of the people in the DARPA ecosystem.

The range of ideas that DARPA has generated run the gamut from esoteric formulas, machinery, and chemical reactions to social interactions. This breadth is a testament to the fact that the military, its branches, and the other government agencies that directly engage DARPA are driven to a significant extent by the priorities, needs, desires, and even whims of the individuals who work in the ecosystem. Proponents point to DARPA successes that everyday Americans make use of, for example, GPS and applications such as Twitter or Facebook (made possible by the internet).[9] The apparent ease with which many of these advances have led to "civilian" applications makes sense: The military is, after all, made up of people. Corralling these ideas, rooted in how we maintain not just an edge but decisive military superiority, however,

[9] A more controversial technology now available to the general public is the AR-15, which was one of the many DARPA-tested weapons systems to emerge out of the Vietnam War.

has not always been either narrowly focused or successful.[10] Throughout the course of DARPA's history, individuals who embraced specific goals and values have contributed to decisions that resulted in bioweapons and nuclear capability (e.g., hydrogen bombs)—innovations that make mass destruction seem quaint. Thus, one of the lessons of the "ideas" space is that it matters greatly who is doing the ideation and what drives them.[11]

Implications for NCADE: The experiences and values of those who are involved in initial ideation are likely to have a significant impact on the agency's outcomes.

Like DARPA, the work of NCADE will be shaped by the individuals who are involved in developing ideas and carrying out the work prompted by those ideas. The agency's direction, foci, and impact will—at least initially—be influenced by those who are most deeply involved in designing it, so it is critical that these leaders represent diversity of thought along with well-informed views regarding the needs of learners and educators. Some level of agreement on what outcomes should be most highly valued is also important. Because equity is a goal of many education R&D projects, for example, it will be crucial to ensure that all involved parties agree on what "equity" means, why it should be a priority, and how it applies to their work.

Explore opportunities to leverage a broad ecosystem of partners and resources at the outset.

Although DARPA has a relatively low staff headcount, the agency has been able to consistently draw on—and is fundamentally reliant upon—vast resource pools the federal government directly and indirectly cultivated.

Between 1970[12] and 1991,[13] DARPA turned an idea about precision munition delivery into the technology and practices that can actually explode ordinance on a pint-sized object from thousands of miles away. Orbital satellites that provide real-time global communication and positioning, integrated chip design advances and miniaturization, stealth materials

[10] Among several of the more public failures are Agent Orange, the Hearts and Minds campaign in Vietnam, and vertical take-off and landing of aircraft.

[11] Jacobsen's (2015) account of the motives of the principal proponents for advancing R&D on a more advanced nuclear device, a hydrogen bomb, Teller and Livermore, suggests they were driven by a deep-seated aversion to communism and a belief in "might making right" stemming from Teller's early years in Europe during the rise of Germany and the Soviet Union.

[12] In May of 1972, after several years of unsuccessfully trying to destroy a key bridge in northern Vietnam, "… a squadron of F-4 fighter bombers equipped with newly developed laser-guided bombs were sent on a mission to bomb the bridge. With several direct hits, the bridge was destroyed" (Jacobsen, 2015, p. 125).

[13] The "Shock and Awe" campaign President Bush launched in Iraq would see the introduction of both high-altitude laser-guided munitions and the introduction of offensive drone technology.

development, and graphical computer user interface advances are among the numerous—multidecade spanning—innovations required to transform these ideas into reality. This complex process offers an important lesson about what replicating the R&D model underlying such an innovation might entail. Some (e.g., Bonvillian, 2018) have described DARPA's R&D model as a "pipeline." However, as a metaphor, "pipeline" is inadequate on several levels. DARPA looks like a small agency with few full-time employees and a short-term rotating roster of intellectual/entrepreneurial project managers, but the agency has an R&D process, a manufacturing and scaling process, and an end-user uptake model that most commercial concerns would envy. Moreover, one rationale for its organizational structure was to eliminate red tape associated with federal bureaucracies. It is, however, important to note that DARPA, and its predecessor, ARPA, initially relied heavily on an established R&D infrastructure that grew out of the Manhattan Project. DARPA was started in an environment that drew on several federally funded R&D shops—namely Lawrence Livermore Labs, Sandia Labs, and Los Alamos Lab. DARPA also relied heavily on a well-established and well-oiled machine in defense contractors like Lockheed and Martin Marietta, Raytheon, Northrup, Grumman, and others. These contractors provided important elements for a successful R&D effort: workers who were skilled enough to transform ideation into blueprints, facilities to produce prototypes, and sites to field test them. Additionally, the talent pool, while considerably more diverse today than when it began, grew was able to grow largely via the enormous funding the federal government injected into colleges and universities with the GI Bill, and the broad expansion of higher education into the middle class. DARPA continues to support teams that involve broad networks consisting of university-based researchers and private-sector contributors (Bonvillian, 2009).

Implications for NCADE: The agency's success is likely to be influenced by the partnerships it forms at the beginning and by its ability to leverage other sources of funding.

To promote development that will have broad impact, the ecosystem for NCADE needs to include multiple federal agencies (including, for instance, the Department of Labor, Department of Defense, and National Science Foundation), along with state and local education agencies, universities, research organizations, commercial firms, and eventual users (educators, students, and policymakers). The DARPA experience suggests that this broad ecosystem can help attract top talent while supplying the range of disciplinary and methodological expertise needed to generate high-quality, innovative solutions in a rapidly changing world. These partnerships will help ensure that R&D is aligned with the needs and goals of potential users who will be responsible for scaling.

Prioritize user-focused R&D.

DARPA's successes are grounded in use cases.

Our research suggests that DARPA's success is related to its efforts to ground ideation in use cases (i.e., a description of the ways in which potential users might interact with a product or other innovation). For example, while high-energy focused weapons might sound like imaginative science fiction, the innovations leading to the development and testing of laser-focused energy weapons systems are grounded in real applications, such as providing a means to accurately target a key bridge in North Vietnam[14] or testing speed-of-light energy-focused anti-ballistic platforms on ships, aircraft, and satellites.[15] Having a use-case focus, along with a broad ecosystem of research and scaling capacity, means that these ideas—grounded in an articulation of how they might be used—can quickly be transformed into usable/testable prototypes and soon thereafter practical applications. It is important to note that not all use cases are equal; some ideas are easier to turn into reality than others. A GAO study of DARPA, for example, argued that important predictors of successful technology transfer included the degree of military or commercial demand for the technology along with "active collaboration with potential transition partners" (Government Accountability Office, 2015, p. 12). ARPA-E encourages its grant recipients to develop commercialization plans early in the project lifecycle, and it has developed an infrastructure to facilitate commercialization (Tollefson, 2021). These conditions in turn lead to a "pull/demand" model rather than a "push" or "/solution in search of a problem" model. As we've discovered with many of the consumer advances in technologies during the last decade, the reality is an artful dance between the two models that drives the innovation/adoption process. To help program managers evaluate the potential for a project, DARPA has also made use of what they refer to as the Heilmeier Catechism:[16]

1. What are you trying to do?
2. How is it done today and who does it? What are the limitations of present approaches?
3. What is new about your approach, and why do you think it will succeed?
4. If you succeed, what difference will it make?

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[14] In this instance, "laser painting a target" greatly increased the efficiency of a guided missile over high-altitude carpet bombing.

[15] The use case here relates to the amount of time it takes to neutralize a threat. Typical anti-ballistic systems fire a projectile to thwart offensive missiles. The location where these projectiles are launched from can have a significant effect on their usefulness.

[16] See DARPA 2019 Strategic Framework (Defense Advanced Research Projects Agency, 2019).

5. How long do you think it will take?
6. What are your mid-term and final exams? (i.e., what interim and final assessments will you use?)
7. How much will it cost?

Implications for NCADE: Engagement with the field, including practitioners, policymakers, and researchers in related disciplines, can promote R&D that is aligned with practical use cases.

The importance of close collaboration with the field is clear. But it is important to acknowledge the need for an expansive view of "the field"—one that recognizes the numerous societal and technological factors that influence the lives and work of educators and students. DARPA's commitment to avoiding technological surprises resonates clearly with recent conversations about the role of artificial intelligence (AI) in education practice and research. To take one example, the release of ChatGPT and other tools based on large language models has led to widespread conversations about the potential effects of AI-related advances in education. Many of these conversations have been characterized by a tone of surprise or even alarm, despite the fact that those who have been keeping tabs on R&D related to large language models had been predicting the emergence of this type of tool. If a larger number of education researchers, practitioners, and policymakers had been not just aware of, but engaged with that broader body of AI work, we could be closer to incorporating these innovations into new tools and services to improve teaching, learning, and assessment, and to formulating and enacting the necessary changes to policy and practice that will be needed to reduce the likelihood of harm.

It could be beneficial for NCADE to require R&D projects to develop concrete plans for scaling and sustainability. Teams might propose a path toward commercialization or scaling for noncommercial uses. The development of these plans should not, however, replace the close collaboration with the field discussed above. The approach to user-focused R&D that DARPA and ARPA-E have prioritized, if applied to education R&D, could help reduce risks that researchers create solutions for which there is no demand. In other words, NCADE's work should support solutions that get "pulled" into use because they're meeting a specific need rather than having to be "pushed" into a market that might or might not be interested. The Small Business Innovation Research (SBIR) program provides a potential model.

Apply principles of design-based research.

A design-based approach to R&D facilitated the goal of "failing fast."

In addition to collaborating with potential customers and users, DARPA's and ARPA-E's work benefited from application of design-based research principles. Design-based research emphasizes rapid development and deployment of prototypes, gathering of user feedback, and fast-turnaround efforts to apply that feedback to revise the prototype. It also emphasizes the need to test theories in relevant settings and to engage in continuous improvement based on how the relationships theorized to generate effects meet the needs of users. Close collaboration with the field is important, as it offers opportunities for R&D actors to engage directly with prospective users and other stakeholders. This rapid-cycle improvement approach can contribute to the goal of "failing fast" but can do so in ways that promote ongoing refinement and improvement. In 2022 congressional testimony,[17] DARPA Director Stefanie Tompkins described this approach as follows:

> In recent years, with the democratization and acceleration of technological advances around the world, we have increased our emphasis on rapid prototyping and on faster and lower-cost methods of designing, building, and testing technology not just in controlled settings but in the complex, dynamic, messy real-world environments in which they must ultimately succeed.

Implications for NCADE: Design-based research provides a useful model, but a goal of "failing fast" and rapid testing and deployment of solutions raises considerations related to research ethics.

Education researchers have explored applications of design-based research (see, e.g., Design-Based Research Collective, 2003). A key consideration in the education context is the set of users who will engage in the research. Users will include educators and learners, of course, as well as in some cases, parents, community members, policymakers, and other individuals and organizations. Conducting innovation-oriented, rapid-cycle research can require significant changes to teams' and organizations' cultures and norms. Creating prototypes, deploying them, gathering rapid user feedback, and then modifying the prototypes before starting the cycle again is a different way of working from the way many education researchers are accustomed to doing, and it relies on different approaches to thinking about issues like quality assurance and data analysis.

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[17] See https://www.armed-services.senate.gov/imo/media/doc/PASSBACK%20DARPA_%20Tompkins%20SASC-ETC%20testimony%206%20Apr%202022_DARPA_FIINAL%200031.pdf.

In addition to reimagining the standard approach to research to align with design-based research principles, it will be important to examine related supports such as training programs and proposal review processes. For example, IES might consider new training and apprenticeship opportunities for aspiring researchers to experience this design-based approach or to develop new areas of expertise such as analysis of big data. Research–practice partnerships provide a way not only to promote collaboration but also to allow sharing of knowledge and expertise in ways that might enhance individuals' future effectiveness. There is also a need to explore opportunities to speed up the proposal review process as part of the broader effort to produce timely research and innovations.

A significant part of the education R&D ecosystem is the set of agencies and organizations that contribute to the foundational research base. IES's National Centers for Education Research and Special Education Research (NCER and NCSER) have produced important findings, but applied, translational, user-focused R&D can be based on a broader evidence base. It could be valuable to consider expanding the priorities and approaches of these two agencies in light of the goals of NCADE. The creation of IES in 2002 ushered in a new era of rigorous, high-quality research, with an emphasis on developing interventions and testing their efficacy and effectiveness using research designs that support causal inferences. However, as a 2022 National Academies report concluded, IES's approach to R&D has not allowed for a sufficiently comprehensive approach to designing and conducting research that will meet the needs of educators and learners (NASEM, 2022). The report included recommendations for new methods, designs, and topics such as the use of big data and application of technology to improve measurement. To inform a new ARPA-like education R&D agency, a portfolio of foundational research should be designed to generate evidence that is directly applicable to the highest priority innovations that the agency seeks to pursue. This portfolio could include continued advances in long-standing areas of research such as cognitive science, along with foundational research on AI-related innovations (e.g., new approaches to natural language processing). Moreover, a key contributor to innovation-oriented, design-based research is a new approach to measurement that allows for more-frequent data collection on how well innovations are working and for whom. Foundational research to advance this type of measurement, drawing on advances in technology and measurement methodology, will be essential.

NCADE's leaders will need to grapple with ethical considerations related to identifying appropriate testbeds to facilitate the transformation of ideas into solutions. Because education solutions must eventually be tested with real students and educators, it is crucial to consider who is asked to participate and any potential harms they might be subjected to.[18] To the extent that funded research is intended to improve educational opportunities for traditionally marginalized students, engaging these students in the testing of solutions is crucial. But doing so might expose students who are already disadvantaged to untested, potentially ineffective (or even harmful) programs and practices. Close collaboration and engagement of key stakeholders might help mitigate these risks. Updates to Institutional Review Board regulations and guidance might be needed. Of course, many students—particularly those from traditionally marginalized groups— are already exposed to programs and practices that are not subject to rigorous research. Making the kinds of advances that will meet their needs will require carefully balancing any research-related risks with the very real risks of maintaining the status quo.

Recognize how relationships between the agency and its intended users influence both research opportunities and adoption.

DARPA's tightly coupled chain-of-command system provides opportunities for testing and scaling solutions.

The organizations first in line to benefit from DARPA's ideas—the branches of the military, and eventually the intelligence community, offered spaces and engagements that went far beyond lab and field testing. For example, the Vietnam War zone saw rapid prototyping that significantly advanced a host of ideas, allowing them to be refined in real-world situations. One example is personal imaging augmentation technologies, such as night and thermal imaging gear worn by a soldier Even as this period saw a rapid rise in material technologies, it also saw a rise in efforts to employ human-centered innovations (as previously noted) to gain an edge. Notably, ARPA-E, while modeled on DARPA, lacks the tight connections to testbeds afforded to DARPA via its relationships with the branches of the military.

Implications for NCADE: Successful scaling will require buy-in from potential users and decision-makers, who, in education, are part of many disparate systems.

The U.S. education system is much more loosely coupled (see, for example, Weick, 1978) than the DARPA ecosystem. The majority of spending and policymaking decisions occur at the state and local levels, and school leaders and teachers often have significant autonomy in determining what materials and pedagogical practices they use. A single curriculum purchasing

[18] A "harm" in education might simply be the opportunity cost of a student spending time in a learning activity that is less beneficial for them than another learning activity would be.

decision can receive support or pushback from numerous stakeholders, including teachers, parents, and school board members. Each group can be influenced by a variety of technical, practical, and political factors. Educators and other decision makers must be engaged, rather than commanded, to adopt specific evidence-based solutions.

Education R&D faces additional challenges related to the influence that organized groups such as teachers’ unions and parent advocacy organizations can exert. Efforts to promote buy-in and eventual uptake of research-based solutions can thus benefit from engagement with a variety of groups and individuals. Finally, education researchers and funders have sometimes been reluctant to bring developers (especially those affiliated with for-profit companies) into the work, but collaboration with developers can provide useful intelligence about the market and can potentially increase the likelihood that solutions will scale.

Ensure that program managers bring both substantive and managerial expertise.

DARPA’s model is highly dependent on program managers with both technical and management expertise.

Program managers have tremendous influence over the nature and success of DARPA’s work. To succeed in their roles as lead idea generators and entrepreneurs, these program managers must have deep science/technology expertise and must also be able to manage large, complex systems of contractors—who do everything from software design and electrical engineering to fabrication/manufacturing. DARPA prioritizes having program managers with science and technology expertise. Like many other organizations, DARPA has in the past counted on these experts to bring with them the necessary managerial knowledge and skills or to develop them on the job. Although not all program managers aspire to higher-level management roles, and the reliance on those with academic training to oversee the work has clear benefits (e.g., Dugan & Gabriel, 2013; Tollefson, 2021), in recent years DARPA has started considering managerial skills when hiring program managers.

Implications for NCADE: Effective program management requires a broad range of knowledge, skills, and dispositions.

Those who are responsible for projects and initiatives must bring not just technical expertise, but the ability to manage large-scale projects and large, diverse groups of people. Agency leaders should aim to hire technical experts who have relevant management experience and should offer professional learning opportunities to help managers develop the necessary skills.

Carefully examine trade-offs associated with governance and project monitoring.

DARPA's approach to R&D requires carefully balancing practices that promote rapid, field-relevant innovation with a process that ensures quality and harm mitigation.

To promote "failing fast" and rapid testing and deployment of solutions, agency leaders and managers in DARPA and ARPA-E developed processes for frequent review of projects. In some cases these processes appeared to conflict with the need for efficiency and speed. A National Academies (2017) evaluation of ARPA-E found, for instance, that

> The high-touch nature of project management at ARPA-E is a hallmark of the agency and has been praised by performers. That said, quarterly reporting in terms of required written documentation is currently challenging, depending on the technical context. Given that quarterly written reports are offset in time with site visits from program directors and their teams, a project performer may end up having 8–10 direct interactions with ARPA-E per year (p.12).

The National Academies committee recommended streamlining these processes, limiting the need for extensive written details while maintaining frequent engagement between research teams and program directors. This guidance is consistent with an earlier analysis of DARPA by Dugan and Gabriel (2013), who also pointed out the importance of program managers' willingness to accept deviations from project teams' original plans:

> Planning should be light and nimble. Progress can be assessed by tracking iterations to see if they are converging on goals, revealing dead ends, uncovering new applications, or identifying the need for unforeseen scientific advances. Insisting that a team steadily hit milestones established in initial plans can cause it to adhere to a path that—based on something the team has learned—no longer makes sense.

These recommendations illustrate the need for a governance model that prioritizes agility and oversight.

Implications for NCADE: Reporting and oversight must balance burden with a need for frequent evaluation.

The goal of failing fast and learning from failure requires mechanisms to evaluate progress frequently and systematically. It is critical that any agency devoted to making rapid progress avoid adopting time-consuming reporting processes—a concern that was raised by the NASEM committee's evaluation of ARPA-E. NCADE will need a low-burden but regular process for evaluating the progress that teams are making and for informing decisions about whether to continue projects or allow them to end. Moreover, these decisions should not be made by a single manager but should be informed by multiple decision makers. Again, there is a potential tradeoff here; NCADE will need to avoid overreliance on decision by committee, but high-stakes decisions such as whether to end a project—particularly a relatively large investment—should be informed by more than one perspective. Everyone involved, including both NCADE staff and those who receive funding, will need a clear understanding of the factors that will determine continuation of funding, including how failure and success are defined.

A related consideration is the set of incentives provided to R&D teams and program managers. Incentive systems should reward innovation and field relevance as well as progress and success. The NASEM report on ARPA-E cautioned against the application of pressure to achieve short-term successes, noting that such pressure could hinder the agency's likelihood of achieving its long-term goals. NCADE is likely to face similar challenges, particularly because of how education researchers are typically incentivized. For many researchers—especially but not only those working in academic institutions—career advancement depends in large part on traditional academic productivity metrics such as number of publications and citations. Scholarly publications are crucial for advancing the knowledge base, but excessive attention to them can result in actions that fail to benefit the groups that are most in need of those benefits. In particular, decisions about what "counts" toward measures of scholarly productivity can reduce the likelihood that researchers disseminate their work in venues and formats that meet the needs of learners and educators. Further, there is growing evidence that emphasis on these metrics can hinder risk taking and innovation (Bhattacharya & Packalen, 2020). Although IES is unlikely to single-handedly upend this aspect of academic culture, there are smaller steps that could serve a signaling function, such as awards that are tied to evidence of significant innovation and impact. Such efforts could build on existing IES initiatives, such as the partnership with XPRIZE and the Automated Scoring Challenge (see Schneider, 2022).

Toward Innovation-Oriented R&D in Education: Some Remaining Questions

We have identified several relevant insights based on our review of DARPA and ARPA-E, and have provided some specific recommendations to guide decisions about the design and launch of NCADE. Of course, the experiences of these two agencies are insufficient for providing comprehensive guidance to IES, and several questions remain. A few significant questions are as follows:

1. *How can the federal government and the broader field assess both the costs and benefits of high-risk/high-reward R&D, given the challenges associated with defining and measuring outcomes?*
2. *How can NCADE and R&D teams learn from "failure"—e.g., abandoned projects—to ensure improvement and continued innovation?*
3. *What is the optimal distribution of investment across different types of projects (e.g., small seed funding for potentially promising ideas, large awards for "big bets," translation of previously tested solutions into large-scale market adoption)?*
4. *How can NCADE's work be shielded from the political environment that is affecting education in ways that are quite different from its effects on the energy and defense sectors?*

Conclusion

U.S. education is in dire need of improvement. The needs of learners and educators across the United States are urgent, extensive, and diverse. To meet those needs, education R&D must result in new supports for teaching, learning, and assessment that are equity oriented and effective. Feasibility, cost, and relevance to the local context are also crucial considerations. DARPA and ARPA-E provide models for an approach to R&D that has the potential to generate timely and field-relevant solutions, and it will be important for the design and implementation of a new agency such as NCADE to be informed by those agencies' experiences. At the same time, the differences in contexts across sectors, along with remaining questions about DARPA and ARPA-E, limit our ability to provide evidence-based guidance on all aspects of an innovative education R&D agency. In this brief, we have summarized some key findings, implications, and remaining questions based on a review of DARPA and ARPA-E. We encourage those who are responsible for NCADE to consider these implications while recognizing the limitations of the comparison. Recent advances in technology, combined with ongoing national debates regarding equity, make this an ideal time to explore innovative R&D. It will be especially important to track NCADE's successes and failures as it develops to help refine and expand the guidance offered in this brief.

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