Catalyzing Novel Approaches to Rapid, Accurate, and Affordable Early Cancer Detection

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Abstract: Inspired by the Cancer Moonshot, a dedicated team of professionals worked with leaders across the cancer ecosystem to look for an opportunity to radically reduce cancer mortality globally by focusing on early cancer detection. After an initial survey of cancer innovation, progress, and pitfalls, the team believed that if new rapid, affordable, and accurate early detection solutions were appropriately brought to market, it would be possible to intervene earlier when cancer is most treatable.

An extensive process began, informed by dozens of experts in the cancer ecosystem. The Cancer XPRIZE team designed a prize competition where "the winning team will develop a means to rapidly, accurately, and affordably screen for early cancers where intervention can reduce human suffering."

The following outlines the Cancer XPRIZE's experience using a powerful approach—the radical prize design—to catch more cancers in time to make a difference saving lives, dollars, and suffering.

Key Words: Artificial intelligence, breast, colorectal, diagnostics, early cancer detection, exponential, innovation, liquid biopsy, lung, nanotechnology, ovarian, pancreatic, radical prize design, skin, XPRIZE

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Inspired by the Cancer Moonshot, a dedicated team of professionals worked with leaders across the cancer ecosystem to look for an opportunity to radically reduce cancer mortality globally by focusing on early cancer detection. After an initial survey of cancer innovation, progress, and pitfalls, the team believed that if new rapid, affordable, and accurate early detection solutions were appropriately brought to market, it would be possible to intervene earlier when cancer is most treatable.

An extensive process began, informed by dozens of experts in the cancer ecosystem, to design an XPRIZE in cancer (Fig. 1). The Cancer XPRIZE (CXP) team designed a prize competition where "the winning team will develop a means to rapidly, accurately, and affordably screen for early cancers where intervention can reduce human suffering."

The following outlines the CXP team's experience using a powerful approach—the "radical prize design"—to detect more cancers in time to make a difference saving lives, dollars, and suffering. For the purposes of this article, the authors believe that "radical prize" designs extend beyond simple prizes competitions. A radical prize design is a competition whose design requires, in addition to a prize purse, a process where traditional and nontraditional innovators collaborate to address some of the world's most daunting challenges by leveraging technologies that outpace linear yearly gains in speed or power or similarly are characterized by nonlinear reductions in costs. Participating in the XPRIZE Foundation's Visioneers Summit, the CXP team developed a novel "impact proposal" (prize design) to address critical market barriers and to activate nontraditional stakeholders as well as traditional cancer innovators to leverage exponential technologies to develop early detection solutions. The CXP was the top ranked prize model and deemed "ready for launch." After completing this work, Deloitte continued to support XPRIZE, which has since taken this XPRIZE impact proposal. XPRIZE continues to work with potential sponsors to complete the activities required for launch. These activities include, but are not limited to, refining the prize criterion with scientific advisors, detailing rules and regulations, and ecosystem activation and engagement.

While there is much work to be done to launch the CXP and see the results of this competition, the experience demonstrated the value of radical prize approaches as a means to encourage new thinking, collaborate, transform markets, and accelerate the progress of innovation for some of health care's most important challenges.

LOCALIZED CANCER IS ASSOCIATED WITH HIGHER 5-YEAR SURVIVAL RATES

If detection and diagnosis are delayed, a cancer may advance from highly treatable stages to advanced stages where treatment is often highly toxic and less effective and where the disease, in some cases, is incurable. Furthermore, research from the American Cancer Society (ACS) suggests that 42% of cancer deaths may be prevented by addressing risk factors such as smoking, obesity, diet, alcohol, sun exposure, and poor air quality.[1] In addition to following these helpful prevention activities, our team asked the following question: Are there early detection approaches to address cancer in its earliest stages where treatment may have the greatest chance of success?

Most cancers detected when localized have a considerably higher survival rate (Table 1). Take breast cancer, which when caught in an early stage has a 5-year survival rate more than 3 times higher than metastatic breast cancer.[2] The story is certainly more complex than these numbers tell and assumes that cancer originates from 1 site. However, the fact remains that localized cancer offers a considerably better 5-year prognosis than metastatic late-stage cancers whose complexity is greater.[3]

The constellation of diseases that are cancer has benefited dramatically from scientific progress, translational research, and a productive biopharmaceutical industry. Many of these advances in science are due to the extraordinary work of sponsors (e.g., National Cancer Institute [NCI]), academic and community-based medical and research centers (e.g., cancer centers and research collaboratives), and volunteer and advocacy groups (e.g., ACS and Cancer Research UK). For example, NCI spearheaded the first cancer cured by chemotherapy and the first human gene transfer trial using human tumor-infiltrating lymphocytes, and ACS supported the first treatment with a monoclonal antibody.[4]

The significant reduction in cancer deaths has also been greatly helped by guidelines and advocacy. For example, the ACS's prevention and early-detection guidelines coupled with awareness activities across the ecosystem have dramatically reduced cancer deaths. American Cancer Society's Cancer Prevention

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XPRIZE is a model for radical prize design that can move both minds and markets. One example is the Ansari XPRIZE that created exceptional breakthroughs in human access to space and sparked a whole new industry for private companies.

The Ansari XPRIZE incented innovators across the globe to launch the first private space craft.

The winner, Scaled Composite's SpaceShipOne, received $10 million for its successful launch in 2004 and swung the door for commercial human spaceflight wide open.

FIGURE 1. XPRIZE foundation.

Study, among others, helped cement the causal relationship of tobacco use and cancer, and its subsequent guidelines ensured the public was informed.[5] These efforts combined with the proactive work of the US Food and Drug Administration (FDA) have helped the cancer death rate in the United States drop 26% over the last 2 decades.[6] However, there is much more work to be done.

RADICAL PRIZE DESIGNS CAN CATALYZE INNOVATION IN EARLY CANCER DETECTION SOLUTIONS

As cancer cells divide, replicate, and metastasize, their genetic and underlying signaling complexity increases. Thus, treatments often become more expensive, complex, and toxic as the disease progresses. In a world of 21st-century cancer treatments, many of the tools of detection and diagnosis are stuck in the 20th century. For example, breast cancer is often detected by a mammogram—a tool based on a discovery in 1913 that was further developed into a diagnostic method in the 1950s and made widely available in 1971.[7] Colon cancer is often detected by retrograde colonoscopy, which largely began in 1969.[8] Finally, the somewhat controversial prostate-specific antigen (PSA) blood test was first published in 1979 and received FDA approval in 1986.[9] These are only 3 of many other examples. Each of these tests is both antiquated and has individual challenges: The mammogram is not sensitive enough, the colonoscopy is complex to administer, and a PSA test is insufficiently specific to cancer versus normal or benign disease.

Given the critical difference time makes in cancer's progression, we would expect to see massive amounts of research and development (R&D) investment on early detection and diagnosis. Despite capital investments and advancements in science over the last 5 years in the early detection and diagnosis market, the majority of health care R&D continues to be spent on treatments for cancers often caught in its later stages when it is dramatically harder to treat.

Transforming early cancer detection will require a whole new approach to innovation that can be facilitated by a radical prize design. As defined previously, a radical prize design is a competition whose design requires, in addition to a prize purse, a process where traditional and nontraditional innovators collaborate to address some of the world's most daunting challenges by leveraging technologies that outpace linear yearly gains in speed or power or similarly are characterized by nonlinear reductions in costs (exponential technologies). These tools in the hands of the right innovators may create technical leaps that can bring dramatic changes to a market. Our goal with the CXP was to have winning teams create solutions that generate significant improvements in accuracy, timeliness, cost, and cultural acceptability, in those cancers where early detection saves lives. Ultimately, if we are only able to accelerate the pace of discovery and market adoption by 5 or 10 years, we could save thousands of lives.

Inspired by the Cancer Moonshot initiative in 2016, a Deloitte team had the privilege to work through the radical prize design process used in the XPRIZE Visioneering competition. The Deloitte team along with Singularity University's Faculty Chair for Neuroscience and Medicine and Exponential Medicine's founder and chair Daniel Kraft, MD, and Shawna Butler entered the competition and worked with XPRIZE to create an impact prize design for cancer. Two hundred fifty leading scientists, technologists, artists, politicians, entrepreneurs, investors, and philanthropists evaluated the team's CXP design against 25 detailed design criteria and deemed it "ready for launch" as the top ranked new prize model. Subsequently, Deloitte, XPRIZE, Singularity University, Exponential Medicine, the ACS, and others are continuing to refine the CXP.[10] With the forward thinking of experts and leadership from organizations such as the ACS, the final prize design is being reviewed and refined for maximum impact.

The CXP competition is carefully crafted to create team collaboration and partnerships between groups who would not otherwise work together. The design seeks to activate designers, researchers, garage scientists, developers, industry leaders, social activists, patients, and traditional cancer innovators to team to compete. The winners of the competition will not only invent and discover, but also tackle key barriers and market failures to generate investments to unlock a new market that continues to attract innovators.

One of the core innovations in this prize design approach is its deliberate treatment of the typical pitfalls of overdetection issues associated with new entrants. For example, highly sensitive but poorly specific tests may cause overdetection and perhaps

TABLE 1. Statistical Overview of Cancer Types

	5-y Survival Rate | Stage at Diagnosis							
Cancer Types	**Localized**		**Regional**		**Distant**		**Unknown**	
Ovarian	92.10%	15%	73.10%	19%	28.80%	60%	24.20%	6%
Lung	55.20%	16%	28%	22%	4.30%	57%	7.40%	5%
Pancreatic	29.30%	9%	11.10%	29%	2.60%	52%	4.90%	10%
Colorectal	90.10%	39%	71.20%	35%	13.50%	21%	35.50%	5%
Breast	98.80%	61%	85.20%	31%	26.30%	6%	52.50%	2%
Melanoma	98.40%	84%	62.40%	9%	17.90%	4%	81.20%	3%

*Source: Statistics estimated for 2016 by NCI.

overtreatment. Too expensive tests may render them inaccessible for much of the world. XPRIZE, with its sponsors, is now advancing these criteria to ensure the guidelines of the competition avoid these pitfalls.

WHY NOW: A CONFLUENCE OF TECHNOLOGY, ECONOMIC, SOCIAL, DATA DEMOCRATIZATION, AND POLITICAL TRENDS PRESENT A TIMELY OPPORTUNITY TO FOCUS EARLY CANCER DETECTION EFFORTS

A union of opportunities and advances in business, science, technology, and culture will fuel the work of radical prize designs to catalyze and accelerate innovation.

Any one of these trends represents progress, but breakthroughs occur when they are applied in newly conceived combinations and configurations.

(1) Exponential technologies are technologies that achieve yearly nonlinear increases in power or speed every year and/or precipitous reductions in cost[11] (Fig. 2). Historically, innovation creates expense, but exponential technologies eventually become cheaper at scale and are capable of creating dramatic abundance—a critical feature of rapid, affordable, and accessible early cancer detection.

An oft-cited example is genome sequencing. It costs $100 million to sequence a human genome 15 years ago; it costs $1000 today.[12] Combined with recent progress in isolating and genetically characterizing circulating tumor cells, there are rapidly increasing possibilities for early detection solutions. Add the exponential growth of computing power and artificial intelligence (AI), and even more possibilities emerge. Exponential technology will play a key role in achieving advancements in early cancer detection, and teams that rely on these technologies may create breakthroughs that were previously unimaginable.

(2) Movement in the capital markets reflects the immense potential that exists within exponential technology used in early detection. Indeed, there are already several promising early detection solutions that are taking advantage of these exponential technologies (Fig. 3). There are solutions emerging that analyze human secretions and exhalants to determine the presence of cancer. Some wearables are now being improved with detection technology. Liquid biopsies are continuing to generate attention and excitement in the market while imaging devices are miniaturizing. These detection solutions are encouraging on their own and in combination bring considerable potential.

Examples of exponentials include:

- Nanotechnology
- Additive manufacturing
- Augmented and virtual reality
- Networks and sensors
- Genomic sequencing
- Robotics
- Artificial intelligence
- Cognitive computing
- Quantum optimization

FIGURE 2. Exponential technology.

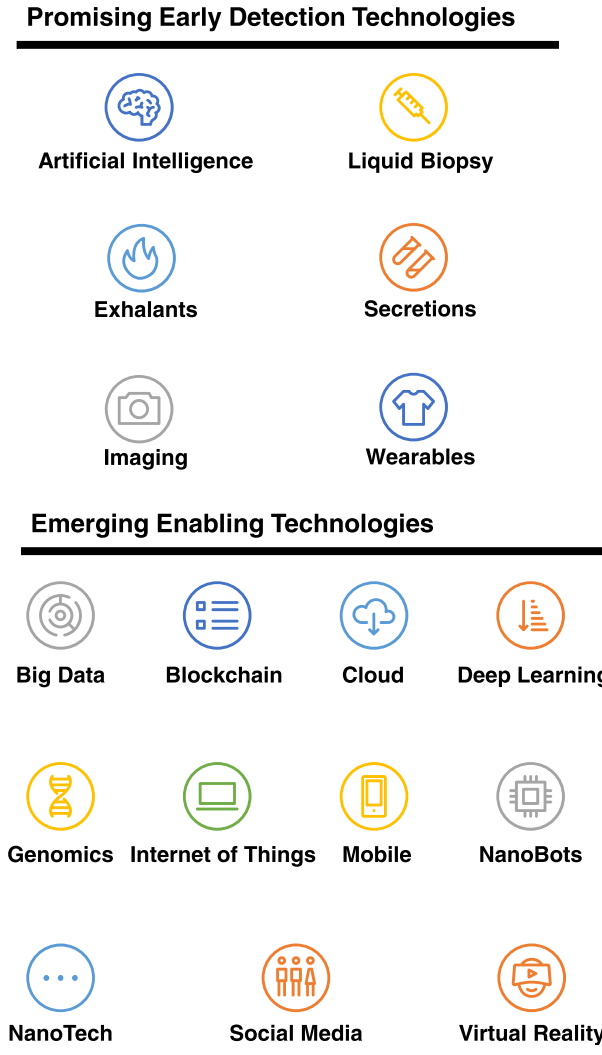

FIGURE 3. Early detection and potential enabling technologies.

Several companies such as Personal Genome Diagnostics,[13] Guardant Health,[14] Freenome, and GRAIL are successfully raising funds in the venture market.[15,16] Glympse Bio[17] is drawing interest with its use of nanotechnology to detect early disease.[18] A Japanese company, Hirotsu Bio Science, recently raised venture funds to support its pursuit of an early cancer detection solution that involves nematodes and urine called N-Nose.[19] In 2014, Cologuard, a noninvasive screening test that analyzes stool DNA and other blood biomarkers for colon cancer, was given FDA approval and successfully entered the market (Fig. 4).[20]

(3) Increased focus on early detection and its role in value-based care. The social cost in lives and suffering and the economic cost in dollars and productivity have reached a tipping point.

A key example of capital that can help accelerate innovations and help bring promising companies to market is Silicon Valley startup GRAIL, which raised $1.1 billion to use high-intensity DNA sequencing to mine blood samples for genetic material shed by hidden tumors.

Liquid Biopsy: Using DNA in Blood to Detect, Track, and Treat Cancer, National Cancer Institute, 8 Nov. 2017, (Accessed January 6, 2018 at https://www.cancer.gov/news-events/cancer-currents-blog/2017/liquid-biopsy-detects-treats-cancer.)
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[23] Cancer Prevalence and Cost of Care Projections. (Accessed January 5, 2018 at https://costprojections.cancer.gov/.)

FIGURE 4. Liquid biopsy.

Envision a scenario in which a patient's health status is monitored around the clock, allowing for insight into early detection and prevention of disease. In one study, researchers were able to predict coronary disease with high accuracy using Twitter feeds.

Eichstaedt, Johannes C., Schwartz , Hansen Andrew, Kern, Margaret L., Park, Gregory, Labarthe, Darwin R., Merchant, Raina M., Agrawal, Sneha Jha, Megha, Dziurzynski, Lukasz A., Sap, Maarten, Weeg, Christopher, Larson, Emily E., Ungar, Lyle H., Seligman, Martin E. P. Psychological Language on Twitter Predicts County-Level Heart Disease Mortality, SAGE Journals. (Accessed January 6, 2018 at http://journals.sagepub.com/doi/abs/10.1177/0956797614557867.)

FIGURE 6. Alternative detection strategies.

Cancer is one of the largest drivers of health care costs that are bankrupting individuals, governments, and businesses. The annual global cost of cancer is estimated to be $2.5 trillion (Fig. 5).[21]

Oncology is seeing an evolution in payment models that move from volume to value. Deloitte's recent report on oncology payment models[22] suggests that pioneering health plans have begun to experiment with patient-centered medical homes and bundled payments. Some of these have already shown a reduction in cost and consistent quality outcomes and in some cases improved outcomes. With the drive toward value over volume, those early detection solutions that decrease cost will likely have pioneering health plans eager to support adoption and reimbursement.

(4) Increased access to massive, novel, and new data sets that allow for unprecedented retrospective analyses. Access to open real-world data (e.g., NCI Genomic Data Commons) along with massive amounts of rich research, clinical, and patient experience data can turn the tide on retrospective analyses. Such data stores will dramatically accelerate the development of cancer screening tools by unlocking years of genetic, tumor, treatment, clinical care, and other patient data sets and exposing them to new computer-based analyses.

Combined with high-end data science methods and cognitive or AI-based computing, data scientists can identify signatures at a fraction of the cost of prospective clinical trial methods. Furthermore, platform trials (e.g., the Public-Private Partnerships LungMAP and QuantumLeap Healthcare Collaborative) and collaborative learning networks (e.g., Oncology Research Information Exchange Network) can provide rapid testing of cancer concepts, treatment approaches, and detection solutions.

Finally, the digital exhaust created from our personal devices, the Internet, and sensors are rapidly being used to detect illness with novel data science techniques. The vast array of data should not only decrease the cost of initial testing, but also may itself become a solution to early detection (Fig. 6).

(5) Increased access to talent, ideas, and perspectives. Oncologists and life science researchers will need access to rare and hard-to-acquire talent to make breakthroughs happen. Using crowd sourcing and prize competition models provides new ways to access an entire ecosystem. Innovating in early detection will require engineering talent, data scientists, computing professionals, epidemiologists, social entrepreneurs, activists, designers, data scientists, AI professionals, testing experts, patient advocates, health care providers, government regulators, payors, and patients who can all work together with traditional innovators in a radical prize design. For example, a scientist may identify the core innovation, an engineer may empower that discovery, and a designer trained in the principles of human centeredness may design the final product shape and

A global investment in the prevention and early detection of cervical cancer could bring tremendous economic value by saving 230 million disability-adjusted life years (DALY). Generically speaking, early detection of cancers can significantly decrease treatment costs; late stage breast cancer costs nearly three times more than early stage. There is clearly an economic and social imperative to innovate in early cancer detection.

The Economics of Cancer Prevention and Control: Data Digest by Union for International Cancer Control (UICC), 2014, December 4. (Accessed January 9, 2018 at https://issuu.com/uicc.org/docs/wcls2014_economics_of_cancer_final.)
Blumen, Helen, Fitch, Kathryn, Polkus, Vincent, Comparison of Treatment Costs for Breast Cancer, by Tumor Stage and Type of Service. Am Health Drug Benefits. 2016 Feb; 9(1): 23–32. (Accessed January 9, 2018 at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4822976/.)

FIGURE 5. Early detection impact.

Take the 17-year-old winner of the Google Science Fair, Olivia Hallisey, who created a portable, rapid Ebola test that works without electricity. Her breakthrough came from discovering a silk fiber derivative that can keep proteins stable without refrigeration.

Kuchment, Anna, Teens Who Won Google Science Fair Took a Leap of Imagination, *Scientific American*. 23 Sep. 2015, (Accessed January 8, 2018 at https://blogs.scientificamerican.com/budding-scientist/teens-who-won-google-science-fair-took-a-leap-of-imagination/.)

FIGURE 7. Diverse sources of innovation.

functionality to enhance the experience and improve adoption. These multidisciplinary teams also serve as sparks for novel solutions.[23] Through collaboration and diversity, the collective perspective is widened and possibilities expand by overcoming inherent biases acquired through whether formal training or life experiences. As such, solutions are more likely to be culturally sensitive and the product of user experience—an imperative for making early cancer detection a routine part of life (Fig. 7).

(6) The health care world is flatter, and patients are increasingly at the center. Thanks to platforms such as social media, patients are able to connect with each other and engage in clinical trials and research pathways.[24] Despite possible concerns, genetic testing companies are seeing significant interest from patients who want to contribute to the larger pool of knowledge about their disease by donating their genomic material.[25] Eager for more rapid progress toward curing disease, patients are no longer passively waiting to be told what to do. For example, a diabetes e-patient is now the principal investigator in a study examining patterns in glucose monitoring data (Fig. 8).[26]

Teams that compete in the CXP will take advantage of all of these existing and emerging opportunities in new combinations. Any one solution could take a very long time to show promise and fall short of widespread adoption, but applying different technologies to the complexities together could accelerate development. For instance, it may be the case that AI solutions create dramatic improvements in timeliness, but not accuracy. It may be that certain circulating tumor cells in liquid biopsies create amazing improvements in specificity, but not sensitivity. It is also possible that tests will detect early disease without understanding the consequences, such as overtreatment.

The radical prize design approach is uniquely built to mobilize talent, resources, and capital in ways that deliver innovative solutions quickly and more affordably. It succeeds where many efforts fail because it activates a crowd of solvers from diverse perspectives and gives them access to tools and data that support finding solutions in previously overlooked places. The result creates a catalyst for massive innovation and sustainable market growth.

ACCESSIBLE EARLY CANCER DETECTION CAN ACHIEVE SIGNIFICANT GLOBAL HEALTH BENEFIT

The most advanced technologies generally are expensive and thus not widely available to people in poor communities or low- or middle-income countries. Typically, those with access to these technologies are more regularly tested to find cancer early and get the most effective treatment. As a result, there is an increase in breast cancer mortality rates among women living in low socioeconomic status areas.[27,28] The NCI Surveillance, Epidemiology, and End Results data show that whereas there is an increased incidence of breast cancer in white women, African American women have a higher mortality rate.[27]

Similarly, low- or middle-income countries may not have the same resources as industrialized economies and have communities that are far removed from health care providers, leaving too many without access to detection. Bangladesh has one of the lowest cancer screening rates in the world, and not surprisingly, breast and cervical cancers are quickly becoming the leading cause of death in women.[29,30] In sub-Saharan Africa, cervical cancer patients often have large distances to travel to receive care, let alone screening. The time and distance can shrink, however, with the advent of the human papillomavirus vaccine and increased use of the cheap cervical cancer screening method, visual inspection with acetic acid.[31] Vaccine dosing and visual inspection with acetic acid screening can be mobilized and come to the patient.[32] The CXP was designed with these disparities and challenges as critical guiding criteria.

In this flatter world, crowdsourcing using prizes or similar game modalities will be an effective way to bring more patients and nontraditional solvers to the innovation table globally. Gamers playing the protein-folding game called Foldit helped unlock the structure of an AIDS-related enzyme the scientific community had spent decades struggling to unlock. Activating the crowd will be key to creating early detection solutions that will work in the real world.

Peckham, Matt. Foldit Gamers Solve AIDS Puzzle That Baffled Scientists | *TIME.com*. 19 Sep. 2011, (Accessed January 6, 2018 at http://techland.time.com/2011/09/19/foldit-gamers-solve-aids-puzzle-that-baffled-scientists-for-decade/.)

FIGURE 8. Crowd sourcing.

A SUCCESSFUL RADIAL PRIZE COMPETITION COULD PROVIDE BROAD AND LASTING IMPACT BEYOND THE STAGING OF CANCER

The question is whether what has previously taken many years to accomplish can be done in a few. The convergence of new thinking and talent that will be engaged with the CXP could help reinvent the way cancer is experienced on a daily basis. The authors' hope is that the CXP will catalyze faster, smarter, and scalable early detection solutions, which will have a global impact.

A global movement of innovation set off by a radical prize design can empower people by limiting the fear of cancer and affording an additional measure of control over their health by putting the power of detection that is affordable, accurate, timely, and culturally sensitive into everyone's hands everywhere, particularly when the cancers detected have a safe and achievable clinical course of action.

Imagine a world in which a smartphone with AI could detect melanoma for anyone, anywhere. This knowledge could prompt excision and chemotherapy, thereby avoiding the suffering associated with a late-stage melanoma diagnosis. Or imagine an affordable paper-based test that could be installed in home urinals or perhaps even replace toilet paper that utilized nanotechnology and a refined diet to monitor cancer. It might be possible at scale in an industrialized economy that populations adopt nanotechnology that could even detect early pancreatic cancer.

Despite important breakthroughs in R&D, cancer is poised to surpass cardiovascular disease to become America's leading killer.[33] It is important to bring the right tools for the job, and these tools must reach patients in time. The radical prize design is a critical approach to accelerate this process at a time where we need more than just discovery. A market revolution is required.

The authors believe this is the beginning and hope that this approach may bring new life to identify transformative solutions for neurodegenerative diseases, chronic diseases, mental health, and other diseases. Based on this experience using a radical prize design to innovate in cancer, one of the world's most intractable problems, it is clear this is one crucial method for solving the world's biggest problems. It is time to activate the crowd and enable them to collaborate to solve huge challenges such as cancer and create change.

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