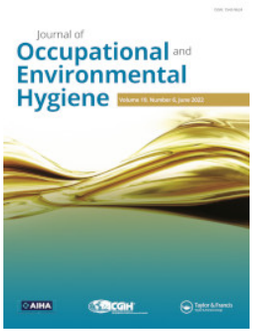

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Applying the CDC Science Impact Framework to the results of the National Institute for Occupational Safety and Health and the Bureau of Labor Statistics 2001 survey of respirator use and practices

Nami Yoon[a], Mary Ari[b], Patrick Yorio[a], John Iskander[b], and Maryann D'Alessandro[a]

[a]CDC/NIOSH/NPPTL, Pittsburg, Pennsylvania; [b]CDC-Office of Science, Atlanta, Georgia

ABSTRACT

During 2001–2002, the National Institute for Occupational Safety and Health (NIOSH), at the United States Centers for Disease Control and Prevention, collaborated with the Bureau of Labor Statistics (BLS) at the United States Department of Labor to conduct a voluntary survey of U.S. employers regarding the use of respiratory protective devices. In 2003, the survey results were jointly published by NIOSH and BLS. This study highlights and evaluates the scientific impact of the 2001–2002 survey by using the Science Impact Framework which provides a historical tracking method with five domains of influence. The authors conducted interviews with original project management as well as a thorough document review and qualitative content analysis of published papers, books, presentations, and other relevant print media. A semi-structured and cross-vetted coding was applied across the five domains: Disseminating Science, Creating Awareness, Catalyzing Action, Effecting Change, and Shaping the Future. The 2001–2002 survey findings greatly enhanced understanding and awareness of respirator use in occupational settings within the United States. It also led to similar surveys in other countries, regulatory initiatives by the Occupational Safety and Health Administration and Mine Safety and Health Administration, and ultimately to a renewed partnership between NIOSH and BLS to collect contemporary estimates of respirator use in the workplace within the United States.

KEYWORDS

CDC; impact evaluation; NIOSH; OSHA; respiratory protection; respirator survey; respirator use and practices; Science Impact Framework; surveillance

Introduction

Where engineering solutions cannot control hazards to an acceptable level, personal protective technologies are needed. Personal Protective Technology (PPT) is defined as the specialized clothing or equipment worn by individuals for protection against health and safety hazards, as well as the technical methods, processes, techniques, tools, and materials that support their development, evaluation, and use (NIOSH 2007b). PPT encompasses personal protective equipment (PPE) such as respirators, gloves, protective eyewear, hearing protection, protective clothing, among others.

Airborne hazards are particularly problematic in occupational settings given the relative ease and speed with which they can affect health and because they can be severely debilitating, with relatively higher rates of morbidity and mortality (Plog et al. 1988). If airborne hazards are not controlled, they are likely to result in chronic injuries and illnesses and/or acute injuries that affect the respiratory system. The respiratory system is a primary route of transmission for infectious agents, such as bacteria and viruses. Respiratory illnesses and diseases caused by exposures at work are a significant problem involving all industrial sectors and account for a large percentage of all occupational disease mortality (CDC 2019).

Given the importance of respiratory protection in occupational health and safety, their technology and use are regulated in the U.S. Since it was established, the National Institute for Occupational Safety and Health (NIOSH) has played a role in respirator testing, approval, and research (42 CFR 84 2002). Both the Occupational Safety and Health Administration (OSHA) and Mine Safety and Health Administration (MSHA) require that NIOSH-approved respirators be used in occupational settings. The effectiveness and continued improvement of research, standards and technology

CONTACT Nami Yoon NYoon@cdc.gov NIOSH, 626 Cochrans Mill Rd., Pittsburgh, PA 15236, USA

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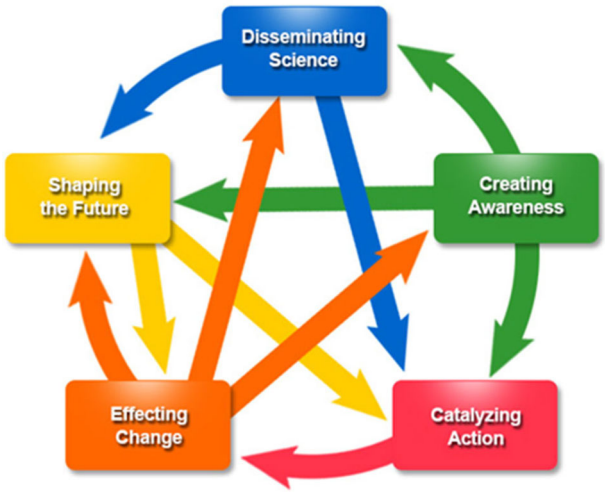

Figure 1. CDC's Science Impact Framework. [Source: CDC SIF website https://www.cdc.gov/os/impact/framework.htm]

development, approval processes, and enforcement activities related to respiratory protection require an ongoing understanding of the types of respirators used, the types of establishments that purchase respirators, the types of jobs and occupations that use respirators, why respirators are used, and whether they are managed and used properly to optimize worker safety. Surveillance is necessary to understand the industry sectors that use respiratory protection, evolving workplace hazards that respirators are used to control, and where deficiencies in safe and optimal use exist.

NIOSH and other government agencies such as OSHA and the National Center for Health Statistics conducted or commissioned surveys on respirator use in the private sector between 1978 and 2000 (NIOSH 1978; NIOSH 1988; DHHS 1994; OSHA 1994; NIOSH 1996; OSHA 1999). Limitations of these surveys led to NIOSH's decision to sponsor a national survey of respirator use in the workplace (Campbell et al. 1998; Doney et al. 2005). These events led to a partnership between NIOSH and the Bureau of Labor Statistics (BLS) to undertake the first national survey of respirator use and practices (SRUP) among U.S. private sector employers in 2001 (NRC 2008) with the objective to estimate the number of U.S. establishments and employees using respirators, determine why respirators are being used, and examine how U.S. employers manage respirator use.

The results of the 2001 SRUP were jointly published by the BLS and NIOSH in 2003 (BLS and NIOSH 2003) and revealed important insights into respiratory hazards and respirator use in the U.S. Using data collected from over 30,000 U.S. establishments (see online supplemental materials, A.1), it was estimated that 281,776 establishments required 3,303,414 U.S. workers to rely on respirators for protection from injuries and illnesses due to respiratory hazards (BLS and NIOSH 2003).

Following the 2001 survey, much effort was devoted toward communicating its results with stakeholders and a review of the effort was completed in 2008 by the National Academies' National Research Council (NRC); however, its scientific impact has not yet been formally evaluated. Evaluating the scientific impact allows for NIOSH's efforts to disseminate the results of the 2001 SRUP to be formally documented, tracked, and an assessment made regarding the research, policy, and regulatory responses prompted by the original research. This paper aims to report the results of a research effort designed to assess the impact of the 2001 SRUP, including how it highlighted the need for focused research, product and standards development, and innovations in conformity assessment.

Methods

Science Impact Framework

We employed the Centers for Disease Control and Prevention (CDC) Science Impact Framework (SIF), an approach that was developed to demonstrate and measure the impacts of scientific work, as an organizing framework to assess the impact of the 2001 NIOSH/BLS survey. CDC's SIF is a systematic method for tracing and linking science to events and/or actions with recognized influence (CDC 2014a). This framework is an extension of the Institute of Medicine's (IOM) "Degrees of Impact" framework (Ari et al. 2020). CDC's SIF can be used to track the impact of any body of scientific work, including programs or portfolios (CDC 2014b; Trivers et al. 2015). Instead of heavily relying on traditional bibliometrics (e.g., citations), the SIF takes the broader societal, environmental, cultural, and economic value into consideration, uses diverse indicators blended together to form a narrative, and includes both quantitative and qualitative data (CDC 2014b; Trivers et al. 2015).

An application of the framework begins with a point of scientific significance. With this starting point, forward and backward links are identified in order to trace the influence (CDC 2014a) (Figure 1). The ultimate goal for public health initiatives is to foster positive health outcomes. However, it takes time for the impact of a body of work to be apparent. Therefore, the framework emphasizes indicators that are likely associated with long-term improvement in health outcomes (CDC 2014a). In tracing influences,

Table 1. Domain of influence and key indicators.

Domain of influence	Key measurable indicators
Disseminating science	Publications, Federal and consensus standards, Professional meetings/conferences, General communication (social media, web, print), Presentations, Training, coursework, Other scientific output (CDC Public Health Grand Rounds, Vital Signs, Science Clips)
Creating awareness	Continuing education, Awards, Stakeholder resources, curriculum, or training, Feedback (survey, focus groups, anecdote), Information sharing, communications among professional societies, Electronic communications (information shared on listservs, social media, news coverage), Queries, Requests to contribute to efforts that further science output
Catalyzing action	Technology creation, New funding (pilots/research), Advocacy groups/NGOs, Congressional hearings, Partnerships and collaborations, Research and development, Office practice/point of care changes
Effecting change	Building public health capacity (e.g., workforce development, funded research, improved staff competency), Creation of registries/surveillance, Legal/policy changes, Accreditation, Cultural/social change, Behavioral change, Economic change, Centers for Medicare & Medicaid Services (CMS) reimbursement, Other payer actions, Change instilled, (New) formal guidelines and recommendations (e.g., World Health Organization [WHO]), Hospital standards, Funding, Anecdotes/case studies, Sustainable and scalable science translation
Shaping the future	New hypothesis/continuous quality improvement, Implementation of public health programs/initiatives, Health outcomes, Prevalence and incidence, Morbidity and mortality (e.g., frequency of outbreaks, trends), Life expectancy, Quality of life improvements, Reductions in economic burden

[Source: modified from the CDC SIF].

there is more emphasis on contribution rather than attribution (it is difficult to assign credit to any single entity). Within the framework there is also a focus on the way the scientific or research knowledge was used.

The framework incorporates a flow of five domains. Each domain defines a degree of scientific impact or influence. An activity or event that shows scientific influence can be categorized as one of the five domains depending on the degree of its impact.

- *Disseminating Science* represents sharing and communicating knowledge with the scientific community, industry, or policy makers initiated by the knowledge producer. Potential measurable indicators for this domain of influence include journal publications, presentations at conferences or meetings, communication through media or website, and other dissemination efforts (CDC 2014a, 2014b; Ari et al. 2020).
- *Creating Awareness* represents "further dissemination and dialogue by the knowledge user, and acceptance of a concept or findings by others" (Trivers et al. 2015, 953). This domain of influence captures evidence that there was an uptake of knowledge—characterized by active involvement of knowledge by users as opposed to the knowledge producers. Key measurable indicators include information sharing and communications among professional societies, knowledge users who cite the original publication in the literature, receiving feedback through surveys or focus groups, continuing education, or requests to contribute to efforts that further science output (CDC 2014a, 2014b; Ari et al. 2020).
- *Catalyzing Action* is characterized by specific actions taken as a result of the adoption of knowledge. Key indicators include technology creation based on the adopted knowledge, partnerships and collaborations, policy advocacy or Non-Governmental Organization (NGO) activities, or further research and development (CDC 2014a, 2014b; Ari et al. 2020).
- *Effecting Change* reflects changes to current or existing situations, directions, strategies, policies, or practice (Trivers et al. 2015). Potential measurable indicators include changes in policy, culture or behavior, society, and economy as well as funding a program or project, or creation of registries or surveillance (CDC 2014a, 2014b; Ari et al. 2020).
- *Shaping the Future* is characterized by the implementation of new strategies or programs to further improvements and changes (CDC 2014b; Trivers et al. 2015). Key indicators include health outcomes, reductions in economic burden, new hypotheses generated, continuous quality improvement, or the implementation of public health programs or initiatives (CDC 2014a, 2014b; Ari et al. 2020). Table 1 presents examples of indicators for each domain of influence.

The framework provides a historical tracing method with five domains of scientific influence that may not be chronological. Therefore, events captured may not be reflected at every domain. The indicators listed under each domain are examples and may be used in creating narratives. Key indicators are listed for each domain of influence to track and qualify events at each domain of influence (Table 1).

Data and analytic approach

Measuring the scientific impact of the 2001 survey includes an in-depth review of published material that referenced the survey or resulted from the survey as well as a review of non-published activities and events. Identification of the sample of published and non-published material and events and coding them was an iterative process. We first started by conducting two structured and documented interviews with NIOSH staff who oversaw the administration of the 2001 survey. The interviews uncovered documented evidence of how NIOSH used the SRUP estimates to engage labor and industry in strategic initiatives and partnerships and uncovered 27 distinct publications (Supplement A.2) that were, in part, designed to communicate the results of the initial survey. These publications are marked as in the reference section.

We, then, traced citations of each of the 27 initial NIOSH publications used to disseminate the 2001 survey results using Google Scholar, Web of Science, and other relevant scholarly databases. When a paper was not traceable through one of the databases, we searched its title via Google search engine to identify possible citations.

Each of the publications that directly referenced one of the initial 27 publications as an important aspect of the work presented was reviewed and the following information was recorded: the authorship; the type of publication (e.g., peer-reviewed article, trade journal, dissertation or thesis); and how the SRUP was discussed within the document (e.g., whether the SRUP was simply used as an evidence of the burden of respiratory hazards in the U.S., or whether the SRUP influenced the study design and data collected). An in-depth, full document review was conducted for nearly all publications. Abstracts were reviewed in a limited number of instances (5) where the full-text publications were not accessible through the scholarly databases or a general internet search. After reviewing each paper, its domain of influence was then determined and recorded. The coding for each document was determined by at least two of the authors of this manuscript (Supplement A.3).

The documents published by NIOSH with the purpose to communicate a portion of the results from the original 2001 survey were coded as *Disseminating Science*. Documents that cited any of the disseminating papers as evidence for a fact statement or supporting statement in introduction, background, or discussion section, were coded as *Creating Awareness*. Documents that reported or alluded to using the survey results to inform new research or policy were coded as *Catalyzing Action*, *Effecting Change*, or *Shaping the Future* depending on the level of impact uncovered. To summarize: *Disseminating Science* included publications that reported the survey results; *Creating Awareness* included publications that discussed the survey results as part of the body of knowledge on the topic; and *Catalyzing Action* included publications that based research or policy recommendations on the survey results. Published documents and activities that went beyond *Disseminating Science*, *Creating Awareness*, and *Catalyzing Action* were considered as either *Effecting Change* or *Shaping the Future* where evidence according to key indicators in Table 1 was available.

The coding scheme was iterative. Both reviewers independently coded all documents according to their respective domain of influence (*Disseminating Science, Creating Awareness, Catalyzing Action, Effecting Change, and Shaping the Future*). During the initial coding process, there were some publications that needed discussion between the two coders due to discrepancies in coding (Supplement A.4). In a second round of coding the first and second reviewer discussed each publication and coded a consensus-reached determination on its respective domain of influence.

All non-published NIOSH activities related to the 2001 survey revealed through the interview process were coded in a similar fashion. An extensive archive of non-published documented activities was provided to the authors by two interviewees from the original 2001 SRUP research team who managed the 2001 SRUP on behalf of NIOSH. Non-published activities included documented discussions, reports, reviews, focus group meetings, presentations, etc. Similar to the review of published activities, each documented unpublished activity was described and recorded with the date(s), content analysis of collected documents related to the events and activities was conducted, and the domain of influence was coded by two reviewers based on the key indicators suggested by CDC (Table 1). When coding discrepancies were observed, the reviewers discussed and resolved the discrepancies. See Figure 2 for illustration of data sampling and coding process.

Results

The results of the 2001 survey were and continue to be used by researchers, policy advisors, and regulators to further the mission of protecting U.S. workers from

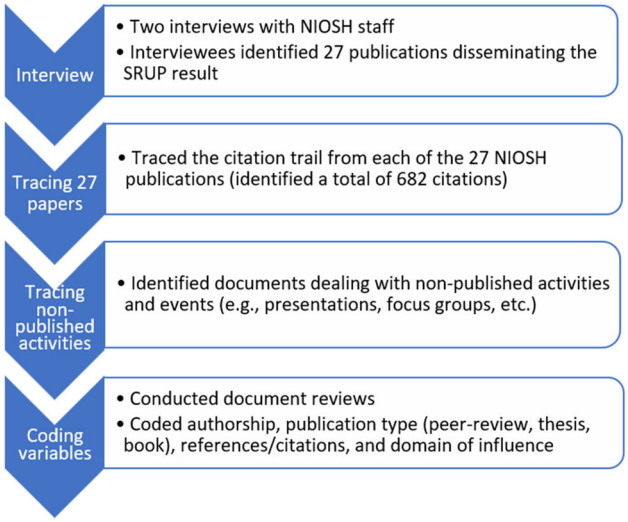

Figure 2. Illustration of data sampling and coding process.

airborne hazards. In the sections that follow, the publications and activities that were classified into each domain are discussed in more detail.

Disseminating science

Publications and presentations

NIOSH actively disseminated and shared the 2001 survey results among industry representatives, academia, and other government agencies via 27 publications. There were two papers that summarize the whole survey results with a high-level overview. First, NIOSH co-published a detailed result of 2001 SRUP with BLS in 2003—the official documentation of the 2001 survey result. This document provided tabulated numeric estimates of respirator use within and across U.S. industries. NIOSH distributed 36,550 CD-ROMs and 5,154 hard copies of this report by 2010. A second publication that provided a holistic overview of the SRUP results was a paper published in 2005 by Doney and colleagues. In this publication, NIOSH researchers laid out summaries of findings across industries and provided an overview of respirator management practices among employers through the lens of federal guidelines. The remaining publications used to disseminate the results of the SRUP were industry specific or narrowly focused on a specific content area. The full list of published material coded as disseminating science (listed and marked as in the reference section) includes documents published in both peer-reviewed journals and trade publications.

NIOSH researchers also used presentations to disseminate the findings from the SRUP. These presentations were conducted at several conferences and meetings (e.g., American Industrial Hygiene Conference, American Occupational Health Conference, National Academy of Sciences, etc.) and were designed to present a high-level overview of the results as well as results customized for specific industries (Supplement A.5). Per a request from the American Road and Transportation Builders Association (ARTBA), the Society for Protective Coatings (SSPC), and the National Demolition Association (NDA), findings were presented at national conferences and published in appropriate trade journals. These findings educated the partners' members to reduce workers' exposures and minimize hazards associated with improper respirator usage. See Creating Awareness and Catalyzing Action sections for activities that transpired from these initial presentations that went beyond disseminating science.

Creating awareness

Publications

Much evidence was uncovered to suggest that the initial efforts to disseminate the results of the survey were received by user groups. A total of 682 references in the literature could be traced to the 27 initial publications used to disseminate the results (Supplement A.6). These publications show acknowledgement and adoption of knowledge by citing the 27 NIOSH publications in their remarks that raise awareness on the importance of respiratory protection and the reality of respirator use in the U.S. For example, AlGhamri et al. (2013, 791) cited the 2003 publication in their paper:

> Safety awareness regarding respiratory personal protection has increased in the USA since that time. As of 2001, the National Institute for Occupational Safety and Health (NIOSH) and the BLS collaborative survey reported that in the USA, there are more than 3.3 million respirator users at 281,776 work establishments for whom respirators are part of their daily work.

In their paper, AlGhamri and colleagues used this BLS-NIOSH publication as supporting evidence for the importance of the proper selection of respirators in the workforce. This contribution belongs to *Creating Awareness* domain because it is characterized as the uptake of knowledge or acceptance of a concept or findings by others (Table 1).

Also, for example, Gosch et al. (2013, 1225) cited Doney et al. (2005) in their introduction and background section in the following way:

> Not surprisingly, the use of respiratory protection in industry and manufacturing is more common than in health care. According to a 2001 survey, respirator

use as a percentage of private sector establishments was less in health care (3.2%) than in manufacturing (12.8%), mining (11.7%), construction (9.6%), or agriculture (9.4%).

In their paper, Gosch et al. used the 2001 survey result to support the argument that the use of respirators is less common the healthcare industry when compared to other U.S. industries. The paper used this evidence to argue that a new respirator for healthcare sector is needed and to argue for the performance characteristics that may be desirable to healthcare personnel. We categorized Gosch et al. (2013) as *Creating Awareness* because the authors used Doney et al.'s findings as basic evidence of the need for a healthcare specific respiratory protective device. A similar pattern was evident in many other papers—they used the survey results as reported in one or more of the initial 27 publications to support their argument, strengthen the importance of their study, or to provide evidence of burden or need for their study.

Focus groups (Supplement A.7)

In addition to evidence of awareness in the published literature, documented evidence revealed that NIOSH worked with two professional associations (ARTBA and NDA) to spread awareness of respirator use and practice in the construction industry based on the 2001 survey results. NIOSH visited road and transportation building sites to see first-hand how respirators were used and information and training were provided to employers during these site visits. ARTBA arranged and NIOSH conducted seven focus groups to discuss the types of airborne hazards present at workplaces, possible control measures used to reduce these hazards, types of respirators used, and barriers to respirator use. NIOSH presented the result of the focus groups with road and transportation builders at the American Industrial Hygiene Association (AIHA)'s annual conference in April 2005. Furthermore, Doney and his colleagues published a study on respirator use among ARTBA member companies based on the 2001 SRUP and ARTBA focus groups (Doney et al. 2009). Moreover, NIOSH conducted similar focus groups with the NDA. During March–November 2004, NIOSH conducted eight NDA-arranged focus groups to discuss the types of airborne hazards present at workplaces, possible control measures used to reduce these hazards, types of respirators used, and barriers impacting respirator use based on the 2001 survey results. NIOSH researchers presented the results of the focus groups to NDA member companies at AIHA conferences in April 2006 and May 2007.

Catalyzing action

Some of the important findings from the survey included: (i) among all establishments requiring respirator use, 95% used air-purifying respirators and 17% used air-supplied respirators; (ii) manufacturing, mining, construction, and agriculture/forestry/fishing had the highest rates of respirator use; (iii) respirators were most frequently used to protect against dusts/mists, paint vapors, and solvents; (iv) signs of inadequate management of respiratory protection among a large portion of the establishments requiring their use (91% had at least one indicator of a potentially inadequate respiratory protection program, while 54% had at least five indicators); and (v) many establishments did not follow NIOSH recommendations and the OSHA and MSHA requirements for the selection and use of respirators in the workplace (Doney, Groce, Campbell, et al. 2005).

It was generally unclear at the time why significant discrepancies existed between the regulations governing respirator use (e.g., fit testing requirements; selection; and program management) and how they were actually used in practice (Supplement A.8). Despite that, it was apparent that diligently communicating this result was important because it encouraged efforts to determine and correct the possible root causes. The results also framed questions regarding why respirator use in some industries was lower than what would be expected given the degree of respiratory hazards that exist. These discrepancies led to several lines of empirical research and development inquiries to improve context specific options for respiratory protection (e.g., Syamlal et al. 2013).

Catalyzing similar surveys

The *Catalyzing Action* domain reflects "the adoption of knowledge resulting in specific actions" (Trivers et al. 2015, 953). Actions include technology creation, new funding/pilots/research, research & development, partnerships and collaborations, and advocacy (Table 1). A good example is international effort to conduct similar national surveys in other countries. In South Korea, a national survey on respirator use in the private sector was conducted in 2007 (Han and Kang 2009). Also, a similar national survey on respirator use in the workplace was conducted in the United Kingdom during 2010–2011 (Bell et al. 2012). These surveys on respirator use in other countries can be

categorized as *Catalyzing Action* because they acquired knowledge from the 2001 SRUP and, as was referenced in the publications, it had some level of influence on the decision to pursue similar efforts in South Korea and United Kingdom. This is evidence that NIOSH's 2001 survey has served as a benchmark against which the reality of respirator use in the workplace can be observed or measured.

Respirator approval program user's notices

The SRUP again reinforced the importance of the NIOSH approval label. The 2004 publication by Doney et al. described the importance of the NIOSH approval label, which led NIOSH to publish a Respirator User's Notice to clarify misunderstandings about the NIOSH approval label (NIOSH 2006). Additional Respirator Users' Notices on the use of replacement and spare parts were published to further clarify the concerns (NIOSH 2007a, 2009a). Five additional Respirator User's Notices were published to alert users to misleading information on the NIOSH labels or describing respirators claiming to be NIOSH-approved (NIOSH 2008, 2009b, 2012, 2014).

National Research Council review and recommendations

NIOSH developed a partnership with the Institute of Medicine (currently, National Academy of Medicine [NAM]) [IOM] and NRC to in part examine the 2001 survey. The dialogue between NIOSH and IOM/NRC began in September 2004 and joint NIOSH-IOM/NRC stakeholder meetings were held during May–August 2005. These efforts contributed to a partnership and collaboration between NIOSH and IOM/NRC to collaboratively catalyze action as a result of the 2001 surveillance effort.

The National Academies found that "NIOSH's PPT Program has made significant strides in improving PPT available to workers, especially respiratory PPT" (IOM and NRC 2008, 17). The recommendations provided by the National Academies include: (i) implement and sustain a comprehensive National Personal Protective Technology Program; (ii) increase research on the use and usability of PPT; and (iii) assess PPT use and effectiveness in the workplace using a lifecycle approach, emphasizing surveillance (IOM and NRC 2008). As a result of these initial collaborations, additional actions were taken by NRC/NAS and NIOSH that could be categorized as *Effecting Change* and *Shaping the Future*.

Strategic research partnership

The 2001 SRUP demonstrated the need for a more developed PPT surveillance program in the agricultural sector. In 2008, NIOSH partnered with Westat, a professional research services corporation, to identify and evaluate secondary data sources for use in meeting some of the PPT surveillance needs. Westat and NIOSH identified three data sources (Supplement A.9) and Westat developed key questions that can be answered by the identified data sources and outlined potential analyses (Supplement A.10). This partnership shaped and guided new research on PPT surveillance and thus its impact is categorized as *Catalyzing Action*.

New research

Numerous publications were categorized as research actions that were catalyzed by the results of the 2001 survey (marked as in the reference section). After reviewing the content, they were classified as *Catalyzing Action* because they referenced the results of the 2001 survey as part of the motivation and rationale behind the new research that was published in the study. We included studies in this category that used the results as a basis for additional research. Two new research areas were developed:

- **Studies of exposure trends and disease association.** Armed with the data from the 2001 survey regarding usage or lack thereof, several studies were conducted that investigated exposure association with certain diseases in occupational settings. For example, Caddell et al. (2007) linked the 2001 survey result with the survey of occupational injuries and illnesses from BLS to explore whether or not there was an association between the quality of respiratory protection program in companies and injury and illness rates. The authors were unable to detect a significant association between the industry level SRUP results and industry level injuries/illnesses and concluded that future studies need to focus on establishments with historically greater potential hazards and health risks and consider the accuracy and completeness of occupational illness reporting.
- **Respirator comfort, fit, and tolerability.** When the SRUP result was published, researchers and policy makers found it surprising that 91% had at least one indicator of a potentially inadequate respiratory protection program and respirator use was lower than expected in some industries and that the reported use of respirators in many

industries were less than expected. This guided research and development into technology of comfort, fit, and tolerability. For example, comfort and tolerability of respiratory protection research (see Supplement A.11) was led by the National Personal Protective Technology Laboratory (NPPTL) within NIOSH and included dozens of publications that directly referenced the 2001 study as a basis for the studies (e.g., Kim et al. 2013, 2015a, 2015b; Roberge et al. 2012a, 2012b, 2013, 2014).

Also, for example, based on the results of the 2001 survey which found that many employers in the U.S. did not properly follow OSHA fit testing guidelines, efforts (Supplement A.12) to improve the fit of respiratory protective devices were led within NIOSH by researchers such as Bergman, Coffey, Rengasamy, and Zhuang of NPPTL (e.g., Coffey et al. 2006; Bergman et al. 2015; Zhuang et al. 2016). Researchers outside NIOSH also used evidence regarding the lack of fit testing from the 2001 survey to expand their research or call for action. Among them, Lofgren, in commentaries published in 2012 (Lofgren 2012) and 2018 (Lofgren 2018), actively called for regulatory actions. In his 2012 paper, Lofgren proposed that NIOSH oversee fit of half mask particulate respirator. Lofgren's two commentaries are clearly an act of advocacy for a new policy and the domain of influence of these two commentaries can be categorized as *Catalyzing Action*. Lofgren (2012, D192) said in his paper:

> If respirator fit testing is so important, have all of the 2 million plus workers using the half mask particulate APR been getting fit tests? The Bureau of Labor Statistics-NIOSH survey in 2001 on respirator use in the private sector found…. The rulemaking proposes significant changes for this most commonly used respirator, with an estimated 2 million workers required to use it in more than 200,000 work sites and over $600 million sales in 2007.

He also argued and proposed that NIOSH approve only good fitting respirators in his 2018 paper. Lofgren (2018, 26) said:

> There also was the assumption that employers, through fit testing of their workers, would identify and not purchase respirators with poor fit…. Subsequent research by NIOSH… have challenged these assumptions. A national survey.… estimated that 43 percent of the employers were not providing required fit tests…. The large number of at-risk workers….would have a greater chance of obtaining one that fits if only 'good fitting' models were certified.

Effecting change

Effecting Change includes evidence of "changes in current or existing situations, directions, strategies, policies, or practice" (Trivers et al. 2015, 955) that resulted from the 2001 SRUP. It also includes the creation of new registries/surveillance initiatives, legal/policy changes, cultural/social change, behavioral change, economic change, change instilled, (new) formal guidelines and recommendations, new standards, funding, case studies/anecdotes, and sustainable and scalable science translation (Table 1).

OSHA/MSHA warnings and rule change

Based on the results of the survey both OSHA and MSHA issued hazard alerts or letters to warn employers about the dangers of specific industry hazards and provide information on how to protect workers exposed to those safety and health hazards. The 2001 survey indicated many employees use air-line respirators (Supplement A.13) but are unaware that the couplings must be incompatible with non-respirable gas or air outlets. Based on the 2001 survey result, OSHA (Supplement A.14) and MSHA issued health hazard alerts on air-line respirators to inert gas supplies in April 2004. Furthermore, the results of the 2001 survey were used by OSHA in the 2006 revision of the respiratory protection standard (Supplement A.15). Another significant point highlighted in the survey concerned the fact that few workplaces conducted air sampling as part of their respiratory protection program. NIOSH provided input on how OHSA regulation can accommodate this concern and OSHA considered these points and updated 29 CFR 1910.134 Assigned Protection Factors (APFs) in 2004.

National Research Council review and recommendations

Based on NRC recommendations concerning PPT surveillance (see Catalyzing Action section), NIOSH held stakeholder meetings to discuss PPT surveillance in March 2008. Based on these meetings, NIOSH drafted a PPT surveillance action plan, describing the Surveillance Strategy for the PPT Program enabling the National Personal Protective Technology Laboratory (NPPTL) to responsibly use the systematic and ongoing collection of data as an input to program decisions, in May 2009. Moreover, NRC recommended further research on PPT use and usability.

NIOSH conducted and published numerous studies on this topic (e.g., comfort wearing, fit testing, and tolerability as described in Catalyzing Action section).

Respirator approval program internet resources

NIOSH website resources were developed to clarify the meaning of the NIOSH approval label to provide users tools to identify if a respirator is NIOSH-approved (NIOSH 2020b). These resources include infographics and website content updates to provide clarity around topics of interest to various stakeholders. Furthermore, updates to the NIOSH Certified Equipment List (NIOSH 2020a) were made to provide users more detailed information about NIOSH-approved devices. These internet resources were updated to address those SRUP responses indicating uncertainty about the NIOSH approval label.

A new standard on respirator fir capability

Since the 2001 SRUP, the need for standard on respirator fit testing had been discussed in research and development circle (Lofgren 2012, 2018). Nearly 20 years after the survey strides to increase the inherent fit capability of respirators, including filtering facepiece respirators, are still underway. A series of scientific studies was conducted by NPPTL to develop new respirator fit test panels, demonstrate correlation between panel cell and respirator size, determine panel size or number of test subjects, inter-panel variability, and pass/fail performance requirements for respirator fit capability test of half-mask air-purifying respirators (Zhuang et al. 2007, 2008; Landsittel et al. 2014; Zhuang et al. 2016, 2017). At the request of NIOSH, ASTM International developed and published a voluntary consensus standard (Supplement A.16) on respirator fit capability test method (ASTM F3407) in October 2020 (Coffey et al. 2021). The NPPTL research results provided the key scientific basis for this ASTM standard.

Shaping the future

A new survey

In its assessment of the 2001 survey conducted by NRC/NAS, both NIOSH and the BLS were applauded "for undertaking this pioneering data collection in order to improve understanding of respirator use in industry" (NRC 2007, 4). The National Academies further suggested that the survey fulfilled a necessary function of NIOSH's surveillance efforts and recommended that NIOSH continue to address data needs to evaluate and improve the respirator approval program by periodically updating the data to ensure that a current understanding of respirator use in the U.S. is maintained. Consistent with the NRC's recommendation NIOSH plans to again collaborate with the BLS to administer a voluntary SRUP 20 years after the initial survey.

A current comprehensive national survey of occupational respirator use in the U.S. will fill an important contemporary knowledge gap, help prioritize research and development activities, and guide policy and strategy. Numerous small-scale, organization-specific studies across industry sectors conducted since the 2001 survey suggest that occupational respiratory hazards and effective management of respiratory protection programs across industry sectors continues to be a concern (Beckman et al. 2013; Fent et al. 2013; Viegas et al. 2013; Ye et al. 2013; Peterson et al. 2015; Sietsema 2015; Harney and Tapp 2016; McClelland et al. 2016; Ceballos et al. 2017; Chiu et al. 2017; Zwack and Tapp 2017; Stanton and Nett 2019). In addition, newly developed or expanded industries (e.g., oil and gas industry), emerging technologies within existing industries, new and emerging respiratory hazards, and changes in the industrial composition of the U.S. economy also highlight the need for a current understanding of respiratory hazards and the use of respiratory protection at the national level (Hall et al. 2008a, 2008b; Esswein et al. 2013; Couch et al. 2018; Jackson et al. 2018; Thompson 2018; Ramsey et al. 2019). In addition, evidence continues to suggest that respiratory illnesses and diseases caused by exposures at work have trended upward since the 2001 SRUP and continue to be a significant problem in the U.S.—involving all industrial sectors and accounting for a large percentage of all occupational disease mortality (CDC 2016, 2018, 2019; Dwyer-Lindgren et al. 2017).

Collectively, this evidence points toward the need for an updated national survey of respiratory use in the U.S. The motivation to again conduct a national survey of respirator management and use can be directly traced to benefits realized through the pioneering action taken by those responsible for initiating and overseeing the 2001 SRUP. Thus, 20 years after the initial survey, NPPTL again seeks to collaborate with BLS to administer a SRUP. The design of the current effort accounts for lessons learned and evolving public health needs. In addition to the aims of the original survey, the current effort is designed to estimate the impact of the recent pandemic on respirator management, use, and availability and identify opportunities for improving respirator technologies. These estimates

Table 2. Summary of scientific impact of the 2001 survey.

Domain of influence	Activities
Disseminating science	27 publications; 36,550 CD-ROMs disseminated; 5,145 printed copies disseminated; Numerous presentations at conferences, meetings, etc.
Creating awareness	Over 600 references in the peer-reviewed and trade journal literature could be traced to the NIOSH publications and the 2001 SRUP; focus groups between NIOSH and trade groups.
Catalyzing action	Numerous research programs were designed and commissioned directly as a result of the 2001 SRUP results; international influence on similar surveys in South Korea and the U.K.
Effecting change	Based on the survey results, OSHA and MSHA issued warnings on the risks involving the inadvertent connection of air-line respirators to inert gas supplies. The results of the survey were used to inform the 2006 respiratory protection standard.
Shaping the future	Current collaboration between the BLS and NIOSH to again administer a voluntary survey of respiratory management and use in the U.S.

will be derived across and within U.S. industries and occupations. The current effort will also target occupations as well as industries, thereby increasing the resolution and specificity of results and targeted interventions in response.

Following the blueprint established by the pioneers of the initial NIOSH/BLS partnership, focused effort to disseminate the results of the survey through presentations, publications, and industrial/academic/and intergovernmental partnerships will be used to create awareness, catalyze action, effect change, and shape the future. By establishing the current state of practice and opportunities for respirator improvement across industry and occupation high yield endeavors may be targeted for policy, funding, outreach, and education. These endeavors would, in turn, ultimately lead to the health outcomes desired including a reduction in fatalities, injuries and illnesses related to occupational respiratory hazards in the U.S. See Table 2 for a summary of impact of the 2001 survey that was discussed throughout the Results section.

Discussion

Understanding respirator use and practices across industry sectors is the first step to the development and implementation of policies aimed to reduce occupational respiratory hazards in workplaces. In 2001, NIOSH and BLS had conducted the first voluntary national survey on respiratory use and practices in the private sector. The survey revealed that large numbers of employers do not follow NIOSH recommendations and OSHA and MSHA requirements for the selection and use of respirators, potentially putting workers at risk (Doney, Groce, Campbell, et al. 2005). NIOSH disseminated the survey results via diverse channels such as websites, publications, CD-ROMs, hardcopies, media, etc. (*Disseminating Science*). Awareness of the survey results were generated and observed through the numerous references in the literature and the integration of the results by various trade organizations (*Creating Awareness*). Numerous new research and development activities, policy recommendations, and partnerships and collaborations were catalyzed directly as a result of the 2001 SRUP (*Catalyzing Action*). One notable finding is that there are publications citing the original 27 publications in recent years, although major activities on reporting the survey results were released early on (Supplement A.17). Furthermore, OSHA and MSHA issued health hazard alerts based on the survey results, and OSHA changed its rule (*Effecting Change*). Finally, discussions on the development and implementation of a new survey are underway (*Shaping the Future*). Domain effects are summarized in Table 2.

There are several limitations to this analysis. First, as a secondary analysis, the data source is limited to what is reported by interviewees and publications and not all full-text publications were accessible. Also, there is concern for some degree of measurement error. When determining the domain of influence of each activity, measurement could be biased by researchers due to subjectivity inherited from human nature (observer bias). However, our analysis strategy, including coding by multiple researchers and the procedure used required the team to arrive at consensus, thereby mitigating some of this effect. Last, the scope of this study is limited to the 2001 survey and its follow-up actions taken by NIOSH and non-NIOSH organizations, individuals, and professionals. Although evaluating health impact is ideal, measuring public health outcomes is out of the scope of this paper.

Conclusions

The science impact framework is a useful and effective tool to evaluate the impact of scientific work beyond citations. This framework was adapted to evaluate the effect of a national survey and applied it to content analysis. The adaptation of the framework also

provides an opportunity for improvement in program management to further public health science and practice (Frieden 2014; Ari et al. 2020), especially in describing indicators of contributions that have the potential to impact public health. Our adaptation of the SIF may prove useful to other researchers and program evaluators who are seeking a framework to categorize impacts that have less well-defined and longer time-scale parameters. Furthermore, this framework can be used prospectively not just retrospectively. The science impact framework has been helpful in designing and planning 2020–2022 national survey on respirator use and practice by identifying where NIOSH would like to see impact and how to strategize the new survey to realize impact.

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ORCID

Nami Yoon http://orcid.org/0000-0001-7865-6139

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Appendix

Semi-structured interview questions

1. Could you briefly describe your roles in 2001 SRUP?
2. How did NIOSH disseminate the results?
   a. How did NIOSH work to communicate the results to different industrial sectors?
   b. Were these efforts fruitful—did industrial sectors use the information to implement changes or notices?
3. Did the survey results identify any gaps that lead to the development of new research or any other programs?
4. Did the survey results identify any gaps that lead to the development of new rules or revised rules?
5. Did the survey results identify any gaps that lead to the development of new enforcement programs or emphasis?
6. Was the data made public or released on request? If on request, please share information on data requests and secondary use of the data.
7. What other actions were taken to influence progress? E.g., guidance documents, trainings developed
8. Do you know of anyone else that we should interview who was involved in the follow-up from the previous survey?
9. Could you share any documents that could help identifying impact of the 2001 survey?