RE-INVIGORATING HIBAR RESEARCH FOR THE 21ST CENTURY: ENHANCING FUNDAMENTAL RESEARCH EXCELLENCE IN SERVICE TO SOCIETY

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ABSTRACT

More than ever, society needs research breakthroughs to address major problems. Universities have a key role to play in discovering the required new knowledge and guiding its application. However, since World War II, universities have been encouraged to focus mainly on *curiosity-based* research, with corporations carrying out *practical* work. This division worked well in the last half of the 20th century, when there was considerable funding for long-term research in the laboratories of major corporations. Today, however, those firms face greater competition, and the resultant financial constraints have foreshortened their research time-horizons. Universities are poised to compensate by re-emphasizing long-term, application-oriented research, but great care must be taken to strengthen fundamental research as well. These objectives can be achieved simultaneously by bolstering a time-honored class of research projects labelled "Highly Integrative Basic And Responsive" (HIBAR), which combine fundamental and applied approaches through partnerships with practical experts. This will help replicate, within universities, the breakthrough-generation capacity that once flourished in major corporate laboratories. Toward this end, a network of universities called the HIBAR Research Alliance (HRA) has recently formed to strengthen HIBAR research, by helping universities to encourage it (while also improving equity, diversity, inclusion, and academic freedom), and by helping researchers to carry out HIBAR projects (while also advancing their careers). The HRA aims to increase the rate of HIBAR projects in universities, from about one project in 20 today, to one in 5 by 2030, while strengthening all types of research excellence.

Key words: innovation, university research, Pasteur's Quadrant, use-inspired basic research, technology transfer, innovative front end, non-university partners, interdisciplinarity

INTRODUCTION

Many human activities have been advanced by applying research methods to identify possible improvements and guide their adoption. It is interesting to contemplate whether *research itself* can also be improved in this way. An often-referenced example of such thinking is the post-WWII report of the US presidential science advisor Vannevar Bush, entitled "Science: The Endless Frontier" [1]. Bush reviewed various research practices and recommended freeing university researchers from considerations of use, so they could focus on purely curiosity-based research. Accordingly, society would rely mainly on the private sector for practical research.

Overall, this separation of curiosity-based and practical research worked very well in the subsequent decades of the 20th century, during which long term research thrived in the corporate laboratories of AT&T, Xerox, IBM, GE, 3M, Honeywell, and others. This kind of research, in such settings, produced many important breakthroughs. It was also very expensive, but the costs could be justified by the large profit margins arising from those firms' strong market positions and the diversity of their business interests. Eventually, though, enhanced competition reduced those margins, benefiting consumers but also limiting the funds available for deep, long-term corporate research [2] [3]. (While this paper focuses mainly on the North American research environment, we recognize that research activities, and the factors that influence them, are increasingly global, and future work should further encompass the international context.)

These trends are problematic because society faces growing global challenges that require long-term, highly innovative, practical thinking. Here, we argue that the only viable solution is for universities once again to participate significantly in long-term applied thinking and, critically, to do so in a way that *strengthens* their fundamental research. These two objectives can be simultaneously achieved by enhancing a specific time-honored class of research projects, recently named Highly Integrative Basic And Responsive (HIBAR). This name was proposed by participants in inter-university workshop on this topic, convened by the Association of Public and Land-grant Universities in January 2017 [4], and reviewed at a workshop of the Government-University-Industry Research Roundtable, in June 2017. The name HIBAR helps signify that these projects combine fundamental and applied research in an integrative and recursive manner. Every HIBAR research project includes deep collaboration with an expert who works outside the university system and is familiar with relevant practical problems of interest. Deep collaboration with practical experts helps to replicate, within universities, the idea-generation capacity previously found in major corporate laboratories.

HIBAR research projects have always existed in universities, but they have been somewhat rare. Nevertheless, there are numerous excellent examples, and efforts are now underway to encourage many more HIBAR projects.

Here we describe HIBAR research and its value in addressing major societal problems. We also consider possible ways to increase the overall quality and quantity of HIBAR research in society. In particular, research universities will need to play a much more central role, and not in isolation.

We also describe how a new network of universities – the HIBAR Research Alliance (HRA) – will cooperate with large existing organizations to catalyze a substantial increase in the prevalence of impactful HIBAR research throughout the university system.

SOCIETY'S GROWING NEED FOR TRANSFORMATIVE SOLUTIONS

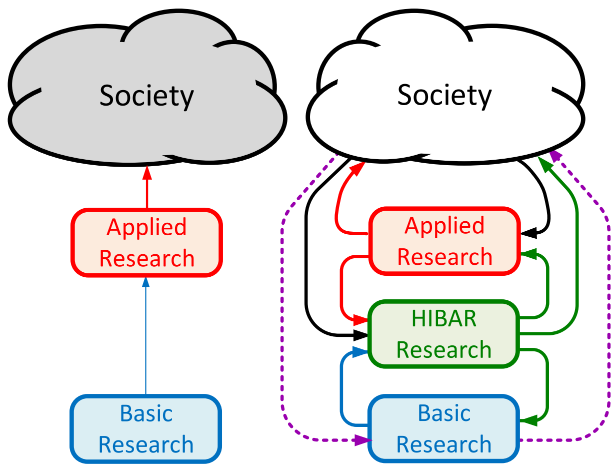
The successes of 20th century research, such as revolutionary breakthroughs in information technology, materials research, and medical treatments, led to significant improvements of many aspects of human wellbeing. For example, poverty rates have declined significantly, life expectancy has increased, democracy and human rights have flourished, education has advanced, and the average rate of violent crime and warfare has steadily declined. These trends provide solid ground for optimism about the future [5].

Unfortunately, society also faces growing threats on multiple fronts and has few clear paths for overcoming them. Democracy itself is being challenged by trends in communication technology. Greenhouse gas increases are likely to cause significant and problematic climate changes. Antibiotics are losing their potency. Worldwide travel and population density have increased the likelihood of global pandemics. Violence, poverty, and environmental degradation, among other factors, have produced a refugee crisis of unprecedented magnitude [6]. The threat of nuclear destruction looms large once again. Environmental degradation is accelerating and threatening agricultural productivity, while the population growth rate continues largely unabated [7].

There is a key connection between these positive and negative factors: The aforementioned improvements largely resulted from humankind's 20th century research breakthroughs, whereas the new major threats of today require *new breakthroughs*, and it is unclear how they can be achieved. How can we ensure that our research enterprises *will* generate the breakthroughs needed to ensure a continued positive future for us all?

HIBAR – A RESEARCH STYLE FOR TRANSFORMATIVE INNOVATION

Before addressing this question in detail, it is helpful to consider an often described, but highly unrealistic view of the transfer of research discoveries into practical application, as depicted in Figure 1a. In it, basic research occurs in isolation, with experts contemplating the laws of nature and the higher-level phenomena of life and human society. Occasionally, some of the findings of basic research appear to have the potential for practical usefulness, so they are transferred to applied research, which adapts them for application and then transfers them to a passive, grateful society. While simple and appealing, this model is not the dominant manner in which valuable breakthroughs for society occur [8].



(a) (b)

Figure 1. (a) A symbolic depiction of a weak, linear relationship in which basic research leads unintentionally to ideas that transfer into applied research and ultimately benefit society – sometimes described as the *linear model* for technology transfer. (b) A depiction of a more effective approach in which HIBAR research is bi-directionally coupled to society and to basic and applied research projects via multiple feedback loops.

In reality, most major breakthroughs arise within the relationships depicted in Figure 1b, in which HIBAR research spans the gap between basic and applied. There are multiple feedback loops: with society, with applied research, and with basic research. In general, emergent phenomena often arise in complex systems with multiple feedback loops [9]. With HIBAR research, the emergent phenomena are often breakthrough discoveries that greatly benefit society [10] [11].

We will now consider the characteristics of HIBAR research in more detail, as a guide toward increasing its overall quality and quantity.

HIBAR Research has a Clear, Specific Definition

It is difficult to pinpoint the origins of today's understanding of HIBAR research, but most agree that Donald Stokes made a key contribution in his book *Pasteur's Quadrant* (1997) [12], which brilliantly brought into clear focus, for broad audiences, a body of work that innovation economists and science policy scholars had written about for decades [13]. Unfortunately, Stokes died shortly thereafter and so was unable to publicize this work directly. Nevertheless, it is highly cited and has been very influential.

Put simply, Stokes espoused the power of investigations that combined the characteristics of basic and applied research. He described these in the 2X2 matrix depicted in Figure 2a, using famous surnames to label these approaches: "Bohr" for basic, "Edison" for applied, and "Pasteur" for the combined form of inquiry, which Stokes named "Pasteur's Quadrant" research. Others have used the term Use-Inspired Basic Research for this idea [14].

Stokes described how, after World War II, presidential science advisor Vannevar Bush recommended freeing university researchers from considerations of use, so they could focus on purely curiosity-based research. According to that plan, society would rely mainly on the private sector for practical research, which worked well during the last half of the 20th century, when long-term applied research thrived in the research laboratories of highly profitable major corporations. Over time, however, their long-term research funding had decayed. Thus, Stokes saw a need for universities to increase their involvement in Pasteur's Quadrant research.

As an introduction to HIBAR research, it is helpful to consider two concerns with Stokes' conception of Pasteur's Quadrant. Both arose in a workshop hosted by the Association of and Land-Grant Universities in 2017. Figure 2a shows Stokes' depiction of Pasteur's Quadrant, which some perceive as implying that basic research is a higher calling than applied work. Figure 2b is a fairer picture that avoids that implied bias, by a simple counterclockwise rotation of 45 degrees.

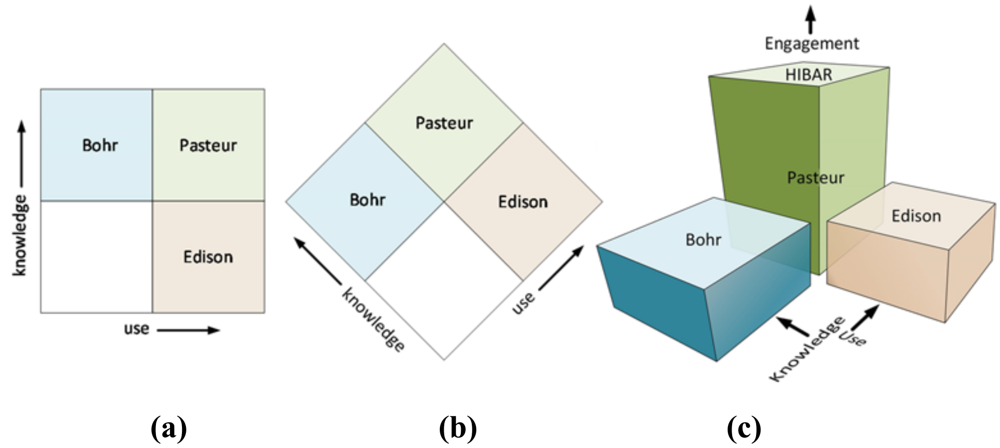


Figure 2. Various depictions of use-inspired basic research: (a) Donald Stokes' original depiction of Pasteur's Quadrant, (b) A rotated version to balance the implied value of basic and applied research without devaluing either, and (c) adding the important dimension of societal engagement.

Importantly, a key component was still missing in that representation of Pasteur's Quadrant research – the engagement of academic researchers with practical experts who are close to the problems being addressed. In short, highly impactful breakthroughs are much more likely when a researcher collaborates, in the planning and execution of a research project, with an expert who has a hands-on connection to a directly relevant societal problem. As evidence of this, the great successes of the major corporate laboratories of the 20th century likely arose because the critical feedback loops depicted in Figure 1b were enshrined within their corporate structure and mission. Notably, feedback loops of this type were deliberately omitted in the arrangement Bush recommended for university research, as shown in Figure 1a.

For these reasons, the name HIBAR was developed to signify these essential aspects and to connote that, contrary to some common misconceptions, HIBAR research is of very high quality. As evidence of this, HIBAR research has generated an unusually large number of Nobel prizes [15]. It led to the transistor, penicillin, and, indirectly, the internet, cell phones, and the GPS system. Importantly, forms of HIBAR research are found in most disciplines, not just in fields such as science, technology, engineering, mathematics and medicine.

Aspects of Integration of:	applied	and	fundamental research.
Motivations:	1) intent to solve problems	*and*	2) desire for discovery
Methods:	3) creative design approaches	*and*	4) traditional investigation
Partners:	5) hands-on practical experts	*and*	6) fundamental researchers
Timeframes:	7) a strong sense of urgency	*and*	8) long-term objectives

Table 1 A 4-category, 8-element assessment chart for identifying HIBAR research projects. HIBAR projects comprise *all 8* of these elements, perhaps not equally, but at least to a significant extent. Particularly interesting are the four shaded items, because they are difficult to *include simultaneously* in a research project, and are especially important.

Table 1 presents the definition of HIBAR research agreed upon by those who developed the term. Notably, a research project is only considered HIBAR if it embodies, to a significant extent, *all* of the eight elements of excellence presented in that table.

For clarity, it should be noted that the HIBAR label is most helpful when describing projects that are neither too small nor too big. At the small extreme, simple research tasks might not benefit from all eight of the HIBAR excellence elements, so the HIBAR distinction might not be useful at that level. At the opposite extreme, some major efforts might contain numerous separate research projects that *as a whole* include all eight HIBAR excellence elements, but *not individually*. In such cases, the *synergy* of those elements would be missing; eliminating the key impact-enhancing aspect of HIBAR research. Depending on the scholarly field, there are different ways to describe the intermediate size range for which the HIBAR distinction is helpful. As an example, in fields requiring research grants, projects in this middle size range might involve one or a few individual grant applications, with one or a few principal investigators and a duration of roughly a few years. In addition, larger projects could comprise multiple HIBAR sub-projects.

It is important to emphasize that encouraging HIBAR research does not disparage other forms of high quality research. The key point is that HIBAR research projects should *also* flourish, because of their high rate of research breakthroughs that help society.

Aspects of Research Excellence	Definition	Basic Research Projects	HIBAR Research Projects	Applied Research Projects
Generative	Broadly applicable, generating many new ideas			
Brilliant	Thoughtful, creative and visionary			
Explanatory	Providing valuable understanding			
Use-inspired	Motivated and informed by societal issues			
Engaged	Carried out in partnership with society			
Practical	Quickly solving a specific practical problem			

Table 2. Research styles have different patterns of emphasis on the spectrum from theoretical to practical significance. Basic projects emphasize the former and applied projects the latter, and together they leave a gap of emphasis in the middle ground. HIBAR research fills that gap and enables the recursive flow of ideas that lead to breakthroughs.

Table 2 illustrates this perspective and depicts how HIBAR research complements other forms of research, and thus fills a key gap. Various research styles have different patterns of emphasis on the spectrum from theoretical to practical significance. For those familiar with NASA's Technology Readiness Levels [16], this range corresponds roughly to levels 1 through 6. However, we note that Table 2 applies to many fields of research, not just technology.

In general, basic research projects emphasize one end of the spectrum depicted in Table 2, while applied research projects emphasize the other. The two distributions overlap only weakly, so the intermediate portion is often underemphasized. HIBAR research projects have a broader range in this spectrum and they are approximately centered within it. This characteristic is conducive to the aforementioned recursive flow of ideas that generates impactful breakthroughs [17].

Four Illustrative Examples of HIBAR Research Projects

To help clarify the definition of HIBAR research, we present here four examples of HIBAR research projects. They demonstrate the diversity of possible projects within the HIBAR category. Despite their significant differences, they all comprise the eight aspects of HIBAR excellence shown in Table 1. Each example includes a brief introductory paragraph, and then a description of the four HIBAR dualities in motivations, methods, partners and time frames.

Example 1. Heart Failure Prediction

Patients often receive hospital treatment for heart failure and can safely return home, with proper monitoring. Dr. Katherine Kim at UC Davis is tackling a fundamental challenge: determining from limited patient data whether a need for readmission has arisen [18]. Inaccuracies in this assessment are harmful to patients. Dr. Kim's approach, applying AI to patient data analysis, is yielding very encouraging accuracy improvements.

Dual motivations: Kim is deeply concerned with the problem of improving patient well-being. Simultaneously, as a scientist, she is fascinated by the prospects of AI in evaluating data provided by patients, and in particular, she has made a fundamental discovery about the objective accuracy of subjective patient assessments concerning their own well-being.

Dual approaches: Kim's work includes data that is provided by patients in their homes, so it has many of the features of traditional patient care, as opposed to research carried out in a highly controlled scientific setting. Nevertheless, her research methods have all the required checks and balances of traditional scientific research.

Dual participation: Kim's research partners span the gamut from leading computer scientists and clinicians to patient participants. These external partners are not just participating in the research – their views are having a critical impact on it.

Dual time frame: Ultimately, there is a very good chance that Kim's research discoveries in this project will have profound positive impact on patients. Naturally, this is a long-term process. If Dr. Kim had restricted her efforts only to short-term improvements, this project would not have taken place. Having said that, her project management efforts have focused urgently on enabling beneficial impact as quickly as possible.

Example 2. Microcredit

A vision and passion for applying First World ingenuity to Third World financial problems began in the readings of a Berkeley law student, Joseph Blatchford, in 1961. A combination of his thoughtful studies, and his personal experiences in travel in Latin America led to an initial plan to launch the organization Accion. This persistence and learning continued and, by 1973, it had evolved into the revolutionary concept of microcredit. This idea has provided financial credit in portions of the Third World economy that had previously been dismissed as unsuitable credit risks. Accion demonstrated an extremely high credit success rate, and slowly the idea of microcredit evolved to the major world force it is today. As an indication of impact, the 2006 Nobel Peace Prize focused on microcredit.

Dual motivations: If Blatchford had only cared about short-term successes, his work would not have carried out the basic research needed to evaluate the merit of this new approach. Thus, the blend of motivation to understand and desire to improve was key.

Dual approaches: Similarly, this synergy of motivations led to the blended approach of studying the problem, *and* taking direct action to solve it.

Dual participation: In this case, the creative drive and energy was located primarily outside of the university system and involved hands-on practitioners, but the successful acceptance of these ideas necessitated high-level participation of established researchers in the analysis of the ongoing results, which likely contributed to the impact [19].

Dual time frame: The dual time frame in this case is illustrated by 50-year time span from Blatchford's first studies to Nobel recognition for microcredit. As with other HIBAR projects, microcredit required urgency with patience – intense action over a long haul.

Example 3. Scanning Tunneling Microscope

The Scanning Tunneling Microscope is a development that arose at Bell Labs Zurich in the 1980s. Its development is largely attributed to work by Drs. Gerd Binnig and Heinrich Rohrer [20], who received the Nobel Prize in Physics for this breakthrough in 1986. Remarkably, the Scanning Tunneling Microscope could have been developed decades earlier, since the underlying technologies had been understood for a long time. Yet no one had previously recognized that the well-known quantum physics phenomenon of tunneling could readily enable atomic-scale resolution of surface structure. All of a sudden, people could "see" atoms. Since then, this technology has had tremendous impact in many areas of science and technology.

Dual motivations: Binnig and Rohrer were embedded in a corporate laboratory that lived and breathed the dual motivations of HIBAR research. They wished to image atoms to understand nature better *and* because they sensed this could lead to solving numerous practical problems.

Dual approaches: Binnig and Rohrer were very experienced at traditional scientific analysis, but their discovery required more than just that – it required a creative leap that was long overdue.

Dual participation: Certainly Binnig and Rohrer represent the research component of the HIBAR duality of participants. The other aspect – involvement of experts concerning problems in society – is less obvious, but according to general accounts of the culture of leading corporate labs of that era, there was regular contact with leaders who directly appreciated present and future technological problems and used that knowledge to help inspire valuable research efforts.

Dual time frame: Had Binnig and Rohrer cared only about rapidly solving an immediate problem to financially assist their company in the short term, they probably would not have developed the scanning tunneling microscope – it would obviously take a long time to have its immense practical impact and might not directly help their employer. If their goal had simply been scientific research, they could have pursued other projects that had a greater chance of yielding new knowledge. From this perspective, their discovery is a perfect example of the intermediate time range addressed in HIBAR research projects.

Example 4. Sustainable Aquaculture

This is a project currently underway by Dr. Ron Hardy in the Aquaculture Research Institute (ARI) at the University of Idaho [21]. In essence, his project's goal is to develop a genetic understanding of the challenges of carrying out widespread aquaculture of fish in a sustainable manner. A key concern is that some of the most valuable fish for aquaculture require non-vegetarian feedstock that cannot be sustainably mass-produced. He and his team are working to solve that problem.

Dual motivations: Hardy has a desire to discover new ideas about fish genetics and nutrition on a basic level and, at the same time, a desire to solve problems of food security for the growing human population in our region and throughout the world.

Dual approaches: Methods for this project include both traditional genetic research related to fish metabolism, and creative techniques for discovering how the biochemical qualities of their normal food (other fish) can be replicated in plant-based fish feed.

Dual participation: Academic researchers at ARI and elsewhere are collaborating with industrial partners from Cargill and other corporations as well as the USDA and other government agencies.

Dual time frame: Long-term objectives include new knowledge about fish genetics and nutrition and urgent objectives include raising more fish to feed more people.

The Rise and Fall of HIBAR Research in the 20th Century

As already mentioned, HIBAR research flourished in major corporate laboratories during the 20th century, but it has faded significantly in these settings at a time when society arguably needs it most. This is an important problem that society must address.

This is an intrinsically quantitative problem (although it arises from qualitative ones). However, only a few quantitative studies related to the proliferation and decline of HIBAR research are available [22] [23]. Nevertheless, some of the key changes are so large that even rough estimates provide useful insights. During the past few years, more than two hundred research experts have attended multiple national-level workshops on this topic and have shared personal observations of approximate trends [24] [25] [26] [27]. They included corporate research leaders, senior university administrators, university researchers familiar with HIBAR research, administrators and researchers from government laboratories, and representatives from both university associations and government funding agencies.

Figure 4 is an attempt to summarize their collective views, in an approximate graphical fashion. We emphasize that this figure has *not* been generated from quantitative research. Rather, it is based on the aforementioned expert conversations and we believe it is approximately representative of their collective observations of these trends.

For simplicity, Figure 4 portrays three example points in time: 1970 (around the peak of corporate national laboratory basic research), 2020 (about now), and 2030 (roughly ten years from now). For each, the portions labeled U represent publishable research carried out by universities, G signifies such research at government research laboratories, and O, research at other organizations, (predominantly corporate laboratories). Within each of those organization categories, the coloring depicts sub-portions of Fundamental, Applied, and HIBAR research.

As mentioned previously, HIBAR research declined dramatically from 1970 to 2020, mainly because of reductions within corporate laboratories. Partly because of legislative changes in the 1980s [28], there was a significant increase of the Applied category within universities, although this did not significantly alter the amounts of Fundamental or HIBAR research. Overall, the key point is this: The total fraction of HIBAR research in society has decreased significantly and this should be corrected to help address the challenges that society faces today.

It seems reasonable that, in response, we should at least replicate the levels of HIBAR research at its peak in the late 20th century, and we should probably go considerably beyond that. To help clarify this goal, consider the future time 2030 depicted in Figure 4. It shows a deliberate increase in the fraction of HIBAR research projects in universities, from 5% today, to 20%. However, this is only one of three possible ways to increasing HIBAR research, so it is appropriate next to consider whether the plan for 2030 in Figure 4 is optimal.

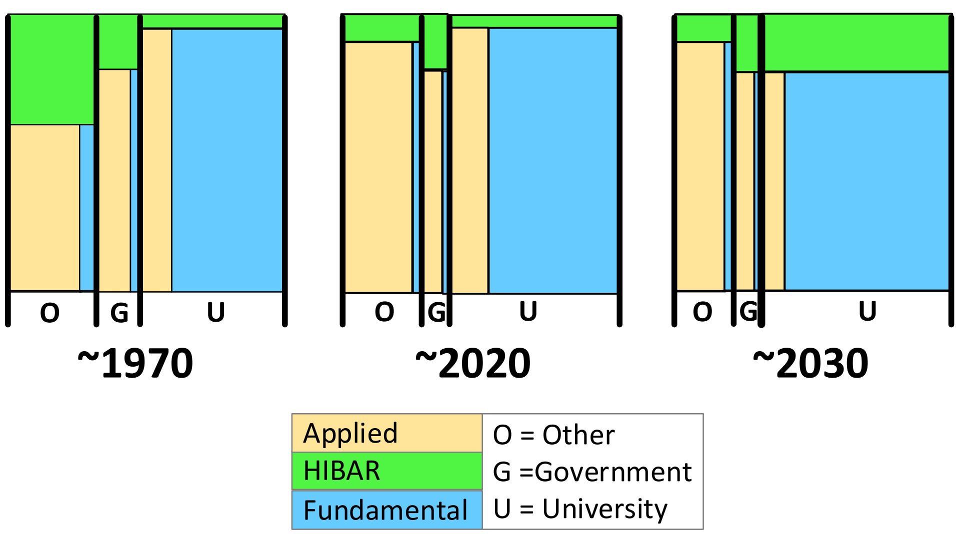


Figure 4. A graphical representation of the relative distribution of research types at about 1970, 2020, and (proposed for) 2030. The figure depicts the approximate relative

research level in Universities, Government and Other organizations, and within each of these, the fraction of projects in Fundamental, HIBAR, and Applied research. A key problematic trend has been the overall reduction in HIBAR research between 1970 and 2020. The proposed compensatory change between 2020 and 2030 would correct this.

HOW CAN WE BEST RE-INVIGORATE HIBAR RESEARCH?

Undoubtedly, there are various possible ways to attempt to increase the frequency of HIBAR research projects. Below, we consider three possible approaches, then we address concerns about feasibility, and we conclude with a recommendation to focus on increasing HIBAR research at universities.

Bring Back the 20th-Century Corporate Research Laboratory? Unfortunately, not feasible.

It is interesting to wonder if the historical corporate investments in HIBAR research were truly financially beneficial for the companies that sponsored that work. In other words, if instead those funds had been directed toward financial investments, would the returns have been better? While we may never know the answer to that question, few doubt that *society, as a whole and on a net basis, benefited from the resultant discoveries*. We also know that companies in that era had greater ability to fund HIBAR work than is the case today, because of strong profit margins that were enabled in part by their strong market positions. When, for example, the US government legislated the break up AT&T, consumers probably benefited from lower prices, but a possibly unanticipated consequence may have been a reduced ability to fund HIBAR research.

This leads to the question of whether governments could modify the regulatory environment to bring back major corporate research laboratories or possibly new equivalents. Indeed, one sector where there have been analogous competitive advantages is software-related enterprises, such as Google and Facebook, and they do support considerable levels of research.

However, their areas of research focus are largely restricted to non-physical studies that are probably less likely to yield solutions to the serious problems facing humankind, such as medical care, energy, environment, social justice, and agriculture. It seems unlikely that we will be able to roll back the clock to the era of the major 20th century corporate laboratories, and thus other solutions must be examined:

Greatly Increase the Size and Funding of Government Laboratories? Also not feasible.

A more realistic alternative may be to look to major government laboratories as steadfast sources of HIBAR research. These have long been environments where HIBAR research has thrived (and fortunately it still does), producing great social benefit. There is no particular reason to doubt that increasing the size and/or number of government labs would be beneficial, since HIBAR research fits well within their culture and they would have a sound base of it to build upon. However, the necessary shift in government expenditure would very likely be difficult politically. Boosting the funding of government laboratory research might come at the expense of university research funding, and the net result would probably be counterproductive. However, increasing partnerships between universities and government laboratories undoubtedly makes sense and could be a beneficial component of an overall plan to enhance HIBAR research.

Increase the Fraction of HIBAR Projects at Research Universities? Feasible and underway.

Fortunately, the third option – increasing the fraction of HIBAR research projects at research universities – is more feasible. It is likely that the shifts depicted in Table 3 for 2030 can be achieved without substantially increasing research funding and without decreasing the overall amounts of basic or applied research. That is because HIBAR projects are *both* applied and basic. Thus, the net result of the proposed emphasis on HIBAR research can be greater success in *both* basic and applied research. From this perspective, the needed change is in a sense a modest adjustment. However, even a small shift within an established system of organizations can be very challenging to achieve.

To summarize, as depicted in Figure 4, HIBAR research today is not rare at universities (it is estimated to comprise about 5% of university research projects), so there is a good base to build upon. In addition, there is plenty of room to increase that fraction without dramatically changing other research priorities. Specifically, we estimate that boosting the HIBAR fraction from 5% of research projects to 20% would be practical, and, at the risk of being repetitious, this would decrease neither basic nor applied research, because HIBAR research contains both of those aspects. Most importantly, the result of increased HIBAR research would be far greater societal benefit. An additional benefit to universities would be that, as society becomes aware of the great contributions they are making, public support for their work would increase.

Let us now consider in more detail how this modest yet powerful shift can be achieved.

A Reasonable Plan for Bolstering HIBAR Research in the 21st Century

To understand the nature of the required change, it is helpful to consider the wide variety of research types underway in modern research universities, as depicted in Figure 5. In this Venn diagram, four key subsets of research projects are depicted: (1) those seeking new knowledge, (2) those aimed at solving societal problems, (3) those taking a long-term approach, and (4) those engaging practical experts as deep research partners. HIBAR research projects are those located within the *intersection* of those four sets, shown as the central box of each of the two drawings in Figure 5. The drawing on the left represents the situation today, and on the right, the goal for ten years from now. In each, the stars represent research projects. Their distribution within the left-hand drawing represents the current situation, in which roughly one project in 20 is HIBAR. The right-hand drawing shows how a modest shift in the overall distribution can yield a 4-fold increase in HIBAR projects, and hence a significant improvement in societal impact. The improved impact is symbolized by showing the HIBAR stars as larger, consistent with the well-established greater societal impact arising from many HIBAR projects.

The changes proposed here are quite likely to be achievable, because they involve simple ideas that individually are common in universities. A good way to make progress along these lines could be to examine new research projects, and consider if they already include most of the 8 HIBAR research elements shown in Table 1. In many cases, only minor adjustments might be required to address missing or under-emphasized HIBAR research elements. For example, a project might only be lacking the serious inclusion of an external practical partner or perhaps only a key component of long-term planning or the inclusion of a relevant supportive aspect of basic research.

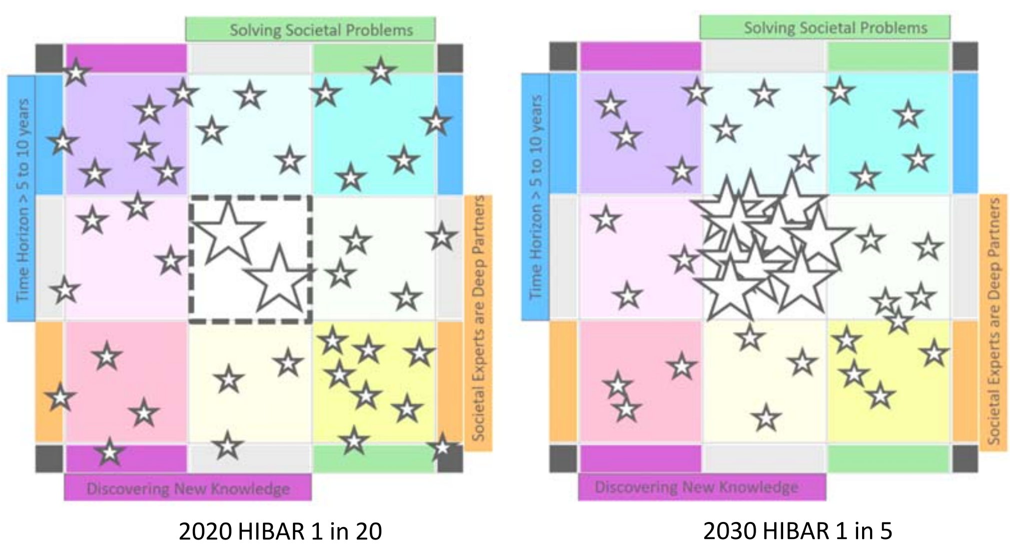


Figure 5. A symbolic representation of a ten-year shift in the distribution of research project types. Going from 2020 to 2030, the overall number is largely unchanged, but the fraction in the central zone representing HIBAR projects increases from 5% to 20%.

In summary, it is desirable and possible to increase the fraction of research projects that are HIBAR. However, is this transition *practical*? That is, can it be achieved with available resources, and if so, *how*?

THE CHALLENGES OF ORGANIZATIONAL CHANGE EFFORTS

There is a discouraging theme throughout the substantial literature on organizational change – most change efforts fail, if not immediately, then eventually through gradual reversion [29]. Fortunately, however, the primary causes for failure are avoidable: Change leaders often significantly underestimate the required *intensity and duration of the effort* and/or they are unaware of *known best practices* for overcoming common change impediments. To avoid these pitfalls, it is helpful to understand related issues of organizational culture.

Bolstering HIBAR Requires a Small Shift in the Culture of the University System

Achieving an important organizational shift, such as that depicted in Figure 5, usually requires a change in *organizational culture*. This term is often defined as the set of underlying beliefs, assumptions, values and ways of interacting that contribute to the unique social and psychological environment of an organization [30]. Groups of people with a high rate of internal interaction often develop an organizational culture that is surprisingly resilient. This is usually a good thing – organizational culture tends to be self-correcting and thus impervious to external influences that could be harmful. (This human trait was probably beneficial for our ancestors.) Because of this characteristic, even modest culture change efforts require great care, so it is helpful here to briefly review some best practices for leading change that have arisen from research on this topic.

Following Established Methods for Ensuring Success with Change Efforts

When designing an organizational change effort, it is helpful to understand two oftenunderappreciated requirements for success. (1) Change efforts must persist with sufficient intensity and for enough time to establish a "new normal", whereby the majority perceive the new state of affairs as an improvement that is worth defending [31]. (2) Change efforts should integrate top-down administrative efforts with a strong grass-roots component that includes, from the start, numerous active supporters throughout the organization. John Kotter has been a strong advocate of this combination [32] [33] [34].

It is also important to consider where culture actually resides. Notably, the culture of a single university does not reside entirely within it, because two key aspects are spread throughout the university system as a whole. (1) Reviews of departmental performance, submitted manuscripts, grant proposals, and promotion & tenure cases are provided, appropriately, mainly by faculty members at *other* universities. (2) Researchers frequently relocate from university to university (indeed, the university culture tends to encourage this largely beneficial activity). Therefore, attempts to change the culture of a university are unlikely to succeed in isolation. It is much more practical if many universities simultaneously work to improve in similar ways.

A "top-down" approach is a needed to gain traction system-wide, and a critical enabling factor is "grass roots" networking of respected individuals at all organizational levels. Such a process must involve interactions within groups that are small enough to developing trusting relationships, and sufficiently numerous to be influential system-wide. These requirements might seem to be in conflict, but there is now a promising way to carry this out, which arose from work on safety improvement within hospital systems [35], and has also been adopted in educational contexts [36]. It is known as the Networked Improvement Community model and has been generalized in a recent description termed a Distributed Network of Collaborative Teams [37] [38].

This is depicted conceptually in Figure 5, which represents a system of similar institutions that could benefit from system-wide improvement. For example, they could be hospitals, fire departments, museums, or, as considered here, research universities. Distributed Networks of Collaborative Teams have important common characteristics: Almost all of the work is done by small collaborative teams whose members voluntarily invest discretionary time because they believe in an overall improvement goal and they believe their team will contribute meaningfully toward it. These collaborative teams are *large* enough to be diverse and to keep manageable the required individual effort level. They are also *small* enough to encourage the growth of trust and mutual understanding among the participants. Generally, the members come from a variety of institutions, both from within the network and beyond, and from a range of operational levels. (As an aside, these labels can vary. Below, we will describe a network that calls itself an "Alliance" which has labeled its collaborative teams "Collaborative Action Groups".)

The collaborative teams have varied objectives that, in combination, enable the network to achieve its important overarching goals. They naturally fall into two categories, according to the aforementioned top-down and grass-roots distinction. The top-down teams primarily help to organize and motivate the organization as a whole, developing various aspects of strategy and thereby creating opportunities for the emergence of grass-roots teams that carry out the bulk of the organizational efforts.

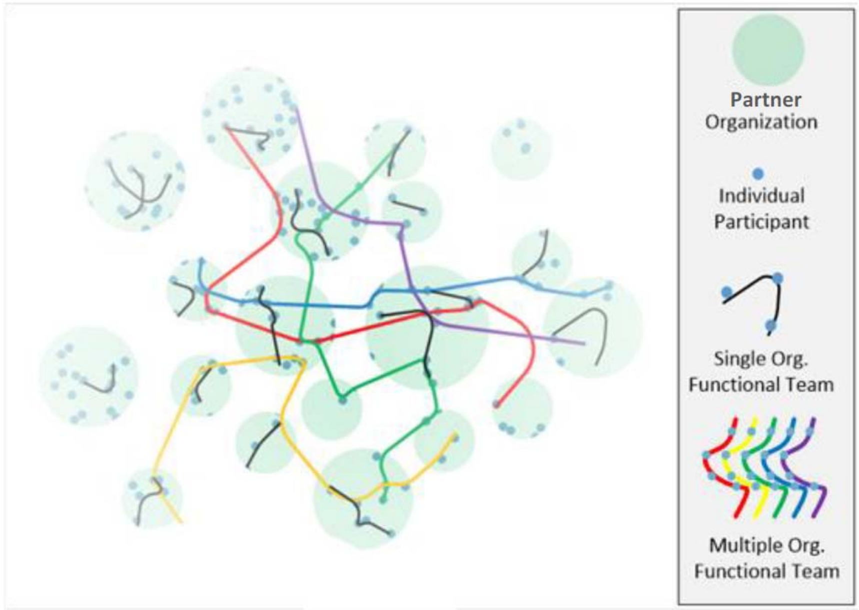


Figure 5. A diagrammatic depiction of a Distributed Network of Collaborative Teams, showing how individuals within multiple organizations form a variety of collaborative teams that are dedicated to specific goals, and whereby achieving all of those goals will fulfill the over-arching goals of the organization as a whole.

INTRODUCING THE HIBAR RESEARCH ALLIANCE (HRA)

The HIBAR Research Alliance (HRA) was established in 2018. It is a small group of universities (currently Arizona State University, Brandeis University, University of British Columbia, University of California Davis, University of Idaho, University of California Los Angeles, University of Maryland, University of California San Diego, University of South Florida, and Washington State University). They are collaborating to catalyze the emergence of an improved academic culture that yields more and better HIBAR research, while improving equity, inclusion, diversity, academic freedom, and all other forms of research excellence. The founding universities have formed a governance council, comprising their vice presidents or vice chancellors for research or a designate, which meets regularly. A key aspect of the HRA is that its change efforts are open to participation from all universities, as well as government laboratories, other government organizations, corporations, and NGOs. The goal of the HRA is to achieve the systemic change goal mentioned above: within ten years, a university-system-wide four-fold increase in the fraction of research projects that are HIBAR.

A Small Organization for Change, Collaborating with Larger Ones

To remain nimble, the HRA is intentionally a small organization, albeit one with considerable reach. For example, the HRA Governance Council recently invited 230 leading experts who had previously expressed interest in HIBAR research and the HRA, and shortly thereafter 54 of them committed to join one or more of four planned HRA Collaborative Teams, as described below. Since then, interest has continued to grow.

Nevertheless, given the size of the university system, it is unlikely that the HRA, on its own, could achieve the required critical mass of supportive individuals throughout the university system. For this reason, the HRA's success will depend on collaborations with larger existing organizations. Ideally, they will have aligned interests and an ability to disseminate broadly the findings of the HRA. A key example is the Association of Public and Land-grant Universities, which supported the discussions that created the HRA. Other possibilities include the National Academy of Inventors, the National Association for Broader Impacts, the Government-University-Industry Research Roundtable, the National Academy of Sciences, the National Aeronautics and Space Administration, the Department of Energy, the National Science Foundation, numerous other research funding agencies, and government laboratories.

Although at present most participants in the HRA are in North America, there is interest worldwide; it seems likely that over time a number of international organizations will wish to become involved. This would help to broaden the narrative presented here to address both historical and present-day global trends.

The HRA's Current Efforts Are Focused in Four Collaborative Action Groups

The HRA Governance Council has established four grass roots Collaborative Action Groups (CAGs) to advance its work. These groups are now working on the following initiatives: (1) helping to make academic incentive structures HIBAR-friendly; (2) encouraging the creation of new HIBAR research projects, especially across disciplines; (3) partnering with related larger organizations; and (4) developing and disseminating better understanding and appreciation of HIBAR research. As previously mentioned, these groups welcome participants from all organizations. During their first few months, the CAGs have developed long-term goals and have selected a short-term action plan that will lead to more advanced initiatives. Here we briefly summarize their initial work.

Collaborative Action Group 1: Promotion and Tenure

CAG#1 focuses on academic incentive systems with a particular emphasis on adapting promotion and tenure processes that will encourage more and better HIBAR research. In effect, the goal is to help universities better reflect their social contract with stakeholders. Guiding the work of CAG #1 is a concern for improving equity, diversity, inclusion, and academic freedom vis-à-vis the promotion and tenure process. The emphasis on academic freedom should enable researchers to focus on helping society when and where they believe it is needed [39].

CAG#1 is initially carrying out a series of interviews with a wide range of participants in the promotion and tenure process at numerous universities, in order to gain a deeper understanding of the current situation and to help identify opportunities for achieving improvements as its work continues.

Collaborative Action Group 2: Initiating New HIBAR Research Projects across Disciplines

CAG #2 aims to catalyze the creation of new HIBAR research projects and, in particular, to promote HIBAR collaborations across academic disciplines.

At this time, CAG#2 is organizing a monthly webinar series. They are inviting researchers from diverse fields to present workshops on how they developed their current HIBAR research projects, the kinds of obstacles they may have faced and overcome (or not overcome), and the advice they would like to offer research administrators and fellow researchers.

Collaborative Action Group 3: Developing Collaborations with Existing Organizations

CAG#3 is leading the cooperative effort between the HRA and other related organizations by identifying key partner organizations and developing mutually beneficial relationships with them.

Currently, CAG #3 is interviewing leaders within a number of likely partner organizations. In addition to exploring specific collaborations, this will help to clarify how the HRA can best add value within the higher education improvement ecosystem.

Collaborative Action Group 4: Disseminating Better Understanding of HIBAR Research

CAG #4 aims to expand awareness, understanding, and appreciation of the value of HIBAR research, and best practices for carrying it out, within a wide range of audiences, both inside and outside of academia.

In its initial stages, CAG #4 has helped to prepare descriptive materials about the nature of HIBAR research, its history and future prospects, and the origin and goals of the HRA. This has included summaries of existing literature, much of which has been cited in this article.

In the future, CAG #4 hopes to encourage new research studies that will add to this knowledge. An example under consideration is the application of artificial intelligence to bibliometric studies of research projects, possibly to assess how the frequency of HIBAR research changes over time.

Invitation to become involved in the work of the HIBAR Research Alliance

The HRA can only achieve its goal of catalyzing improved HIBAR research throughout society by attracting numerous individuals and organizations who share this goal. All interested organizations and individuals are invited to contact the HRA [40].

ACKNOWLEDGEMENT

The authors and current HRA participants gratefully acknowledge the early and ongoing support of the APLU, GUIRR, and NSF, the governance and other in-kind support of the HRA member universities, and the contributions of many individuals who conceived, launched, and contributed to the HRA. This material is based in part upon work supported by the National Science Foundation (NSF) under NSF Grant Number EFMA-1828988 [24]. Any opinions, findings and conclusions, or recommendations expressed in this material are those of the author(s), and do not necessarily reflect those of the NSF.

REFERENCES

[1] V. Bush, "Science, the endless frontier: A report to the President. US Govt. print. off," US Govt. print. off., Washington, 1945.

[2] S. H. Clarke, Challenge of Remaining Innovative: Insights from Twentieth-Century American Business, Stanford: Stanford Business Books, 2009.

[3] J. Gertner, The idea factory: Bell Labs and the great age of American innovation., Westminster: Penguin, 2012.

[4] S. Rovito and L. Whitehead, "Report on the January 26, 2017 Workshop on Advancing Highly Integrated Basic and Applied Research," CIRCLE online repository of the University of British Columbia, 13 Feb 2017. [Online]. Available: http://hdl.handle.net/2429/70436. [Accessed 3 June 2019].

[5] S. Pinker, The better angels of our nature: Why violence has declined. Penguin Group, USA: Penguin Group USA, 2012.

[6] United Nations, "Unprecedented 65 million people displaced by war and persecution in 2015," United Nations, 20 June 2016. [Online]. Available:

https://refugeesmigrants.un.org/%E2%80%98unprecedented%E2%80%99-65-million-people-displaced-war-and-persecution. [Accessed 23 05 2019].

[7] W. V. Reid, "Earth System Science for Global Sustainability: Grand Challenges," *Science,* vol. 330, no. 6006, pp. 916-917, 2010.

[8] D. Sarewitz, "Saving science," *The New Atlantis,* vol. 49, no. Spring/Summer, pp. 4-40, 2016.

[9] D. Kenrick, N. Li and J. Butner, "Dynamical evolutionary psychology: individual decision rules and emergent social norms," *Psychological Review,* vol. 110, pp. 2-28, 2003.

[10] B. Shneiderman, The new ABCs of research: Achieving breakthrough collaborations, Oxford: Oxford University Press, 2016.

[11] V. Narayanamurti, Cycles of Invention and Discovery, Cambridge, MA: Harvard University Press, 2016.

[12] D. E. Stokes, Pasteur's quadrant: Basic science and technological innovation, Washington: Brookings Institution Press, 2011.

[13] D. Sarewitz, *personal communications,* 2019.

[14] Swiss National Science Foundation:, "Use Inspired Basic Research," Swiss National Science Foundation, 1 May 2019. [Online]. Available: http://www.snf.ch/en/theSNSF/research-policies/use-inspired-basic-research/Pages/default.aspx. [Accessed 1 June 2019].

[15] The Economist, "The rise and fall of corporate R&D: Out of the dusty labs," *The Economist,* p. 74–76., 3 March 2007.

[16] NASA, "Technology Readiness Levels," NASA, 1 Jan 2019. [Online]. Available: https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html. [Accessed 1 June 2019].

[17] B. Schneiderman, "Twin-Win Model: A human-centered approach to research success," *Proceedings of the National Academy of Sciences,* vol. 115, no. 50, pp. 12590-12594, 2018.

[18] CITRIS, "Heart Failure Prediction," Center for Information Technology Research in the Interest of Society (CITRIS), 20 May 2019. [Online]. Available: https://citris-uc.org/health/project/non-invasive-multi-sensor-predict-worsening-heart-failure/. [Accessed 31 May 2019].

[19] S. R. Khandker, Fighting poverty with microcredit: experience in Bangladesh., Oxford: Oxford University Press, 1998.

[20] G. Binnig and H. Rohrer, "Scanning tunneling microscopy," *IBM Journal of Research and Development.,* vol. 30, no. 4, pp. 355-369, 1986.

[21] R. Hardy, "Nutrient Requirements of Fish and Shrimp," National Academy Press,, Washington, D.C., 2011.

[22] A. Arora, S. Belenzon and A. Patacconi, "The decline of science in corporate R&D," *Strat Mgmt J,* vol. 39, pp. 3-32, 2018.

[23] L. Fleming, H. Greene, M. Marx and D. Yao, "Government-funded research increasingly fuels innovation," *Science,* vol. 364, pp. 1139-1141, 2019.

[24] S. Rovito, "Highly Integrative Basic And Responsive (HIBAR) Research: Engaging Theory with Practice for Transformative Solutions," Association of Public and Land-grant Universities, 1 April 2017. [Online]. Available: http://www.aplu.org/projects-and-initiatives/research-science-and-technology/hibar/. [Accessed 4 June 2019].

[25] B. Sneiderman, C. Crittendon, S. D and L. Whitehead, "Highly Integrative Basic And Applied (HIBAR) Research: Partnerships in Discovery and Innovation," Governement University Industry Research Roundtable, 2017 June 2017. [Online]. Available: https://sites.nationalacademies.org/PGA/guirr/PGA_180364. [Accessed 4 June 2019].

[26] S. W. L. Rovito, "HIBAR workshop University of British Columbia," University of British Columbia, 1 November 2017. [Online]. Available: http://hdl.handle.net/2429/70629. [Accessed 12 June 2019].

[27] S. Brown, J. Nelson and L. Whitehead, "Report on National Science Foundation Workhop on HIBAR Research and forming the HIBAR Research Alliance," University of California San Diego, 21 March 2018. [Online]. Available: http://hdl.handle.net/2429/70630. [Accessed 12 June 2019].

[28] US Government, "CHAPTER 18—PATENT RIGHTS IN INVENTIONS MADE WITH FEDERAL ASSISTANCE," US Government, 1980. [Online]. Available: http://uscode.house.gov/view.xhtml?path=/prelim@title35/part2/chapter18&edition=prelim. [Accessed 1 June 2019].

[29] J. P. Kotter, Leading change., Cambridge, MA: Harvard business press, 2012.

[30] E. H. Schein, "Organizational Culture," *American Psychological Association,* vol. 45, no. 2, 1990.

[31] J. Kotter and L. Whitehead, Buy-in: Saving your good idea from getting shot down, Cambridge MA: Harvard Business Press, 2010.

[32] S. Elrod and L. Whitehead, "Turning on the Thrive Channel to Accelerate Change in Higher Education," ASCN, 1 February 2018. [Online]. Available: https://ascnhighered.org/ASCN/posts/201117.html. [Accessed 1 June 2019].

[33] J. P. Kotter, Accelerate: Building strategic agility for a faster-moving world, Cambridge MA: Harvard Business Review Press,, 2014.

[34] J. Kotter, "Turning on the Thrive Chanel," Kotter International,, 01 January 2018. [Online]. Available: https://www.kotterinc.com/research-and-perspectives/survive-thrive. [Accessed 3 June 2019].

[35] D. M. Berwick, "Disseminating innovations in health care," *Jama,* vol. 289, no. 15, pp. 1969-1975, 2003.

[36] T. Bryk and e. al., "Getting ideas into action: Building networked improvement communities in education," *Frontiers in sociology of education,Springer, Dordrecht,* pp. 127-162., 2011.

[37] M.-D. Seidel, L. Whitehead, M. A. Mossman and C. Sá, "The Distributed Network of Cooperating Teams (DNCT): A Multi-Level Initiative for Organizational Change," University of British Columba CIRCLE online repository, 6 August 2017. [Online]. Available: https://open.library.ubc.ca/cIRcle/collections/facultyresearchandpublications/52383/items/1.0354236. [Accessed 6 June 2019].

[38] L. Whitehead, C. Sá, D. Sarewitz, M.-D. L. Seidel and M. Mossman, "Co-operative research revolution could answer call to transform science and society," The Conversation, 3 October 2017. [Online]. Available: http://theconversation.com/co-operative-research-revolution-could-answer-call-to-transform-science-and-society-81447. [Accessed 2 June 2019].

[39] J. Daniel and T. Sura, "From “I Still Can’t Work with You” to “Let’s Work Together”: Creating a Rhetoric of Collaboration that Supports Professors.," 1 September 2018. [Online]. Available: https://profession.mla.org/2018/09/07/from-i-still-cant-work-with-you-to-lets-work-together-creating-a-rhetoric-of-collaboration-that-supports-professors/. [Accessed 25 June 2019].

[40] "HIBAR Research Alliance," HIBAR Research Alliance, 1 April 2019. [Online]. Available: www.hibar-research.org. [Accessed 1 June 2019].