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Surveyed impact of intellectual property training in STEM education on innovation, research, and development

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Abstract

This paper analyzes the findings of an international survey questionnaire to which responses were received from over 500 members from different technical societies of the Institute of Electrical and Electronics Engineers (IEEE). The survey is primarily intended to uncover members' perceptions of patent filing and research-driven innovation. Our thesis statement is twofold. First, the introduction of basic intellectual property (IP) courses to university Science, Technology, Engineering, and Mathematics curricula would teach students valuable basics of IP and associated issues, technology protection; and possibly stimulate novel/innovative R&D outcomes. Second, studying relevant active/lapsed/expired patent documents could provide stimulating input for ongoing academic research. After analyzing the survey results we conclude that IP coursework could be a catalyst for students and researchers to explore patent opportunities related to their specific interests. The resulting knowledge would further enable researchers to prepare more compelling funding applications. In our experience, IEEE conference publications are often closely aligned with inventions to solve pressing technical problems. Conference papers typically comprise of cutting-edge research/industry findings, with a short time between paper submission and presentation. Furthermore, conference organizers choose themes representing the forefront of technologies that often lead to inventions. These could fuel patent developments, but academic research environments often provide little if any incentives for academic researchers to prepare and file patent applications. Indeed, the attainment of high impact journal publications remains the primary metric by which research activity is judged and future academic tenure achieved.

KEYWORDS

academic patenting, intellectual property courses, technology transfer, university patenting

1 | INTRODUCTION

1.1 | Overview

This study focuses on intellectual property (IP) awareness in engineering, physics, and associated educational sectors. To this end, we designed a survey questionnaire to test Institute of Electrical and Electronics Engineers (IEEE) members' general understanding of patents and research-driven innovation. From this, we identified optimal intersections between research, invention, patent filing, and existing developments. Setting the backdrop to the survey and touching on a number of the points raised in the survey, the first part of this paper includes a short overview of various historical definitions of innovation and the role of patenting therein. This is followed by a brief discussion of patenting in academia, examining aspects of IP inclusion in Science, Technology, Engineering, and Mathematics (STEM) curricula, institutional drivers for patenting together with drivers and impediments to patenting by individual academics. We then discuss the survey, its methodology, results, and conclusions.

In support of this discussion, Appendix A contains the results of the survey, while Supporting Information Appendix B to the survey contains supplementary materials based on an aggregated view of written comments received in the survey.

With this in mind, our thesis statement is twofold. First, the introduction of basic IP courses to university STEM curricula would teach students valuable basics of IP and associated issues, technology protection and possibly stimulate novel/innovative R&D outcomes. Second, studying relevant active/lapsed/expired patent documents could provide stimulating input for ongoing academic research.

We recognize the distinction between research and innovation, but there can be crossovers between the two domains. While IP is conventionally viewed solely in terms of its contribution to the innovation domain, in some instances the process of applying for patent protection (e.g., reviewing prior art disclosed in or cited against published patent documents) can lead an inventor to new ideas, principles, and technologies that drive their subsequent research.

1.2 | Aims of this paper

Large gaps exist in knowledge and in the published literature at the intersection of innovation, research and development (IRD). Nevertheless, some literature suggests that academic STEM Departments and Law Schools with integrated degree programs could produce a highly skilled IRD workforce (Srivastava, 2013). With more work needed to be done on this subject, our survey aims to assess: (a) novel outcomes in STEM research (e.g., theses, projects, papers etc.); and (b) patent exploitation in STEM research. We use the outcomes of these studies to consider the need for optional or mandatory IP courses in STEM under-graduate and postgraduate degree curricula to foster an IRD ecosystem.

2 | BACKGROUND

2.1 | Innovation

While working as a patent examiner in Switzerland's Patent Office (Galison, 2003), much of Albert Einstein's role entailed examining patent specifications (or patent applications more broadly). It was his exposure to the variety and complexity of inventions for which patent protection was sought, that ignited his interest in and propelled him along the road of innovation.

There are many different and overlapping definitions of innovation. In 1911, Schumpeter defined innovation as "new combinations" of new or existing knowledge, resources, equipment, and other resources; and as a specific social activity undertaken in the economic sphere for a commercial purpose (Schumpeter, 2003). This definition has been followed by many others over the years. For example, Thompson states: "Innovation is the generation, acceptance and implementation of new ideas, processes products or services" (Thompson, 1965). Kimberly describes innovation in terms of its different forms: "There are three stages of innovation: innovation as a process, innovation as a discrete item including, products, programs or services; and innovation as an attribute of organizations" (Kimberly, 1981). Drucker defines innovation as "the specific tool of entrepreneurs, the means by which they exploit change as an opportunity for a different business or a different service" (Drucker, 1985). Similarly, Damanpour describes innovation as a means of changing an organization, either as a response to changes in the external environment or as a pre-emptive action to influence the environment (Damanpour, 1996). In their efforts to establish an integrated perspective of innovation, Baregheh et al. (2009) identified 60 definitions of innovation. However, a common thread among these definitions is innovation's commercial goal. It is this feature which distinguishes innovation from academic research whose main goal is knowledge creation.

2.2 | Patents

Notwithstanding its many definitions, research has shown that patents are closely linked to innovation. Indeed, patent counts are one of the most commonly used proxies for innovation (Jaffe & Trajtenberg, 2002; Kogan, Papanikolaou, Seru, & Stoffman, 2017). For many companies (and most especially technology-based companies), IP (including patents) is critical to their business. Indeed, patents are often a key element of a company's Innovation Management system (i.e., the process within a company/organization that drives the creation of new ideas and concepts with a business value; Williams, 2013) that enables a company to maintain its competitive edge over its rivals in the marketplace.

A patent is a government-issued time and geographically limited monopoly right. A patent does not give its owner the right to practice an invention. Instead, a patent gives its owner the right to exclude others from making, using or selling the claimed invention; and in many cases, it also gives the owner the right to exclude others from importing the invention. This exclusionary right is limited to the country in which the patent is granted and for the lifetime of the patent, which in many cases is 20 years from the earliest filing date of the application for the patent.

In the United States, there are two classifications of patents, viz., "Utility" and "Design." In general terms, a "utility patent" protects the functional aspects of an article (or the way it is used; U.S.C., 2011: Article 35 U.S.C. 101) whereas a "design patent" protects the ornamental aspects of an article (i.e., the way an article looks; U.S.C., 2011: Article 35 U.S.C. 171). Both design and utility patents may be obtained on an article if the invention resides in both its functional/utility aspects and its ornamental aspects. This paper and the survey it discusses are focussed on utility patents.

Utility patents protect new, useful and nonobvious inventions comprising patentable subject-matter, wherein the categories of patentable subject matter consist of process, machine, manufacture, and composition of matter (U.S.C, 2011: Article 35 U.S.C. 101).

An invention's novelty is assessed relative to the background of what has come before. This background information is called "prior art." For an invention to be novel it must not have been patented, described in a printed publication or in public use, on sale or otherwise available to the public before the effective filing date of the claimed invention; or (b) described in a patent or a patent application filed before the effective filing date of the invention.(U.S.C., 2011: Article 35 U.S.C. 102(a)(1)). Prior art also covers pop up prior art which includes U.S. patents, published U.S. patent applications, and published Patent Cooperation Treaty ("PCT") applications designating the United States, that were filed before the effective filing date of the application and published after the effective filing date of filing of the application (U.S.C., 2011: Article 35 U.S.C. 102(a)(2)). These become available as prior art as of the date that they were "effectively filed."

When an invention is novel over the prior art, but the inventor has merely made an obvious modification to the existing body of knowledge, he/she will not be awarded a patent. More specifically, an invention is not patentable if the differences between the claimed invention and the prior art are such that the claimed invention as a whole would have been obvious before the effective filing date of the claimed invention to a person having ordinary skill in the art to which the claimed invention pertains (U.S.C., 2011: Article 35 U.S.C. 103). However, it should be noted that "a patent composed of several elements is not proved obvious merely by demonstrating that each of its elements was, independently, known in the prior art" (United States Supreme Court Cases, 2007: *KSR International Co v Teleflex Inc* 550 U.S. 398, 2007).

2.3 | Patent/IP courses

In this paper, we investigate researcher's perceptions as to whether the introduction of basic IP courses to university STEM curricula would teach students valuable basics of IP and associated issues, technology protection and possibly stimulate novel/innovative R&D outcomes. The survey discussed in this paper does not prove that the introduction of IP into a STEM curriculum would produce these desirable results. Rather the survey explores other researchers' views on the topic. However, it is taken into account that views in themselves are not proof. In support of this, we note that there are several examples where IP knowledge is already part of the teaching curriculum (Clarysse, Mosey, & Lambecht, 2009; Friebe & Traub, 2015; Srivastava, 2013). In connection with this, we note that entrepreneurial activities (which are often driven by and hugely dependent on IP) are receiving increasing attention in technology teaching.

2.4 | IRD in the university sector

Patenting has not traditionally been a focus for many research institutions and Universities. However, in recent years these bodies have come under political pressure to demonstrate and improve their impact on national wellbeing, with focus primarily on economic growth, job creation, and competitiveness, but also to public health and security. Universities receive significant public resources for research and governments increasingly question the return on this investment. Universities are required to demonstrate and improve the economic and societal impact of its research. For example, the EC Horizon 2020 research and innovation funding program requires funding applicants to clearly identify the technological, economic and/or societal impacts of their research; and to include a dissemination and exploitation strategy of the results (e.g., including arrangements for Freedom to Operate searching; IP harvesting and licensing; and the establishment of spin-out companies) in their funding applications (Scherer, 2018).

More broadly, universities are increasingly required to make their research more attuned to the needs of industry and to more effectively link their research to commercial applications. As part of this trend, policymakers have encouraged publicly funded research to smooth the transfer of results to industry by establishing proprietary rights over the research. However, university patenting activity varies widely. Only a small number of Universities are responsible for the vast majority of patenting activity undertaken by the sector in the United States. Indeed, only five individual universities, MIT, Stanford, University of Wisconsin, University of Texas, and Caltech were granted more than 100 patents in 2012.

In keeping with the principle of academic freedom underpinning academic institutional autonomy (Zgaga, 2012), the technological direction and focus of patenting activity of academic institutions is essentially driven by the invention disclosures submitted by academics and researchers. Thus, in considering the institutional advantages of patenting, special consideration must be given to the potential benefits of patenting to academic researchers, which include (Ouellette & Weires, 2020).

2.4.1 | Financial benefits

Academic researchers can financially benefit from University patent royalties schemes wherein the university shares patent royalties with inventors. However, in practice, only a few Universities raise significant income from licensing their patents. In 2012, the top 5% of U.S. earners (eight U.S. universities) took 50% of the total licensing income of the U.S. university system; and the top 10% (16 U.S. universities) took nearly three-quarters of the system's income (Valdiva, 2013). Thus, financial remuneration to researchers from royalty sharing schemes is likely to be quite limited. In connection with this, we note that the literature regarding the significance of financial remuneration as a driver of patenting by academic researchers is quite mixed. In particular, Ouellette and Tutte note the absence of compelling empirical evidence in the United States that increasing the share of royalties to university researchers has a significant effect on university licensing income (Ouellette & Tutte, 2020). By contrast, Hvide and Jones found that Norway's switch from inventor ownership (the “professor's privilege”) to university ownership (with one-third of net income shared with inventors) was followed by a 50% decline in both entrepreneurship and patent counts (Hvide & Jones, 2018).

2.4.2 | Reputational effect

Even without substantial royalties payments, some individuals value patents because their formal governmental certification of the presence of a novel and nonobvious idea, together with the identification of the person as the inventor thereof. Thus, it is increasingly common for patents to be listed on a professor's or researcher's curriculum vitae (Rantanen & Jack, 2019)

Notwithstanding the above, the extent to which individual researchers have engaged in patenting activities has been historically mixed. Of the many reasons for this, we note the commonly held belief that patenting impedes publication and open science more generally. However, Calderini and Franzoni's study showed that patenting is likely to produce a temporary increase in publications, while it does not discourage diffusion in open science, although in some cases the publication of results may be delayed (Calderini & Franzoni, 2004). Furthermore, a survey conducted by the American Association for the Advancement of Science's project on Science and Intellectual Property in the Public Interest found that 62% of IP creators who had attempted to protect it with a patent had also disseminated the technology in some way: 88% of academic respondents had disseminated their technologies either through publishing, informal sharing, or both methods (rather than via licensing) (Hansen, Brewster, Asher, & Kisielewski, 2006).

More important perhaps, a fundamental disconnect has been noted between institutional technology transfer activities and incentives to faculty members in terms of merit raises, tenure, and career advancement (Sanberg et al., 2014). In particular, the authors note that beyond the monetary benefit of licensing, which is small in most cases, patenting offers little or no benefit to a faculty member's merit raises, tenure, and career advancement.

3 | SURVEY

3.1 | Data collection and methods

The aim of the survey was to reveal the perceptions of IEEE members regarding patents and research-driven innovations. To this end, we initially developed our survey questionnaire, and then tested it on a world-wide group of beta-testers from the STEM disciplines. The beta testers included university staff (professors, research deans, faculty directors) and industry professionals. Comments and feedback received from the beta-testers was used to improve and refine the survey questionnaire. For clarity and brevity, the resulting survey questionnaire will be referred to henceforth as the Refined Survey Questionnaire. To ensure the robustness and independence of the survey analysis, the beta testers' responses were excluded from the results of the Refined Survey.

Referring to Table 1, the Refined Survey Questionnaire was then distributed worldwide using the member e-mail lists of various IEEE technical Societies (IEEE, 2020). An announcement about the Refined Survey was included in the Societies' e-newsletters. The announcement informed readers that a study was being performed about the introduction of new patent courses in bachelor and graduate degrees of STEM and preferred topic-selection in STEM research (i.e., the question/topic that a student or professor chose for the student's thesis/project). Accompanying this, the announcement also included a URL link to the Refined Survey Questionnaire page. The Refined Survey was anonymous insofar as responders were not required to specifically identify themselves. However, to facilitate the survey analysis, responders were requested to provide some basic profile information in accordance with the questions set out in Appendix A.1: Tables I–IX. Further questions in the Refined Survey

TABLE 1 Survey methodology details

Data collection started: April 15, 2018
Data collection ended: January 19, 2019
Population: 51,213 worldwide members from the following IEEE societies: • Electron Devices Society (EDS)—10,355 • Power Electronics Society (PELS)—9,873 • Photonics Society—6,252 • Microwave Theory and Techniques Society (MTTS)—10,917 • Education Society (EdSoc)—3,370 • Aerospace and Electronic Systems Society (AESS)—4,941 • Systems, Man, and Cybernetics Society (SMC)—5,505
Response: 522

Questionnaire included compulsory questions (see Appendix A.2: Questions 1–9) and optional questions (see Appendix A.2: Question 10). Responders were also given the opportunity to provide free-style explanatory comments and details (e.g., web links and project titles for their supervised research—see Supporting Information Appendix B) to support their answers. Table 1

3.1.1 | Definitions relayed to responders

To ensure clarity of the Refined Survey Questionnaire and to assist responders in responding thereto, several defined terms were included in the Refined Survey Questionnaire as follows:

3.1.2 | Information relayed to responders

The survey made responders aware of the following details:

(1) Some Patent Office Databases provide patent images and text files available online to the public (e.g., U.S. Patent Office USPTO.gov);
(2) Patents expire usually after 20 years from the date of the first filing;
(3) Most patent offices require patent holders to make periodic payments to maintain patents once they are granted. If the patent holder does not make the payment, the patent and the protection it confers lapses;
(4) Certain patent search websites (USPTO.gov or Google Patents [advanced search feature]) allow users to look for patents that are 20 years old or older, for example, by setting a T-20 year period;
(5) Michigan Tech created an online search tool for all lapsed patents less than 20 years old in the USPTO database;
(6) Even if a patent is lapsed or expired, the inventor may nevertheless have filed other similar related patents;
(7) During an economic downturn firms may cut back on their budgets for Patent Maintenance fees thereby causing their patents/patent applications to be abandoned; and
(8) Some patent offices are suggesting that they might increase their Maintenance fees (by as much as 55%) and there are proposals to increase the frequency of Maintenance fee payments. These factors could cause an increased number of lapsed patents.

TABLE 2 Definitions relayed to responders

"Active patents"	"Patents younger than 20 years for which maintenance payments have been made"
"Expired Patents"	"Patents older than 20 years"
"Intellectual Property (IP)"	"A term that includes Patents/Trademarks/Design/Copyright";
"Lapsed" or Abandoned" patents	"Patents younger than 20 years for which maintenance payments have not been made";
"Open-source"	"Any software or hardware whose source code or design is publicly available for the online community to inspect, modify, enhance, study, distribute, make, or sell";
"Research"	"A task whereby one acquires a deeper knowledge through investigation, testing, analysis or exploration of challenges and problems. In this case, research can include projects, theses/dissertations, case studies, reports, papers or assignments"
"STEM"	"Science, Technology, Engineering and Mathematics"

4 | ANALYSIS OF KEY FINDINGS AND EMPIRICAL EVIDENCE FROM THE REFINED SURVEY

Appendix A to this paper contains profiles of the survey responders and the results derived from the received responses to the Refined Survey Questionnaire. Supporting Information Appendix B to this paper contains the Supporting Information comprising the entire body of free-style written comments provided by some of the survey responders.

4.1 | Profiles of the responders (Appendix A.1)

Referring to Appendix A.1, the profile responses highlight that there is a strong academic research background among the responders. For example, in Appendix A.1: Table VII, 72% of the responders' highest level of experience in Higher Education research or teaching included: professorship, lecturing, or instructing.

Moreover, Appendix A.1: Table IV indicates that 70% of the responders had experience supervising a thesis/dissertation. Similarly, Appendix A.1: Table V indicates that 52% had experience serving on a doctoral committee. We take into consideration that responders who did not supervise a thesis/dissertation, may have supervised other types of research tasks/assessments, such as case studies, assignments, and so forth (see Section 3.1.1 definition of "research" relayed to the responders).

4.2 | Answers (Appendix A.2) and commentary (Supporting Information Appendix B) received in response to the questions of the Refined Survey Questionnaire

Referring to Appendix A.2, Questions 1–4 are fact-finding questions, while Questions 5–10 are opinion-finding questions. Many of the responders also provided comments explaining or elaborating on their answers to some of the questions. With respect to Questions 1–3, three lists of project titles/web links were volunteered by the responders (see Tables I–III in Supporting Information Appendix B). The following is a breakdown and interpretation of the responses to the survey questions and their related commentary.

Question 1. What is your greater expectation when selecting research topics for students?

Question 1 shows that 46% of the responders who selected a research topic for students stated that they expect students to pursue novel/innovative outcomes, while 37% stated that they expect students to develop new research skills, and 17% stated that they had never selected a research topic for students. It should be noted that the answers are likely to be at least partly dependent on the academic level of the relevant project(s), since it is a qualification requirement for a PhD candidate, for example, that they make a novel or inventive contribution to the state of knowledge embodied in the project area.

Question 2. Have any of your selected research topics led to students filing for patent protection?

The majority of responders stated that none of their selected research topics had led to filing of a patent application (26% Yes, 57% No, and 17% never selected a research topic for students). However, this result is perhaps somewhat unsurprising bearing in mind the academic profile of the respondents and that (as mentioned in the introduction to this paper), delivery of a high impact journal publication is still valued higher for an academic CV than a patent/patent application.

However, it should also be noted that the process of filing patent applications can incur substantial financial costs for a university or academic/research institution. Universities and academic/research institutions typically have a limited budget for patent filing; and the budget may not stretch to cover the costs of filing patent applications for all of the inventions developed by their academics/researchers. In this case, the university must choose which of the inventions the cost of filing patent applications should be incurred. In making their selections, Universities and academic/research institutions recognize that all inventions are not patentable and/or cannot be commercialized (i.e., to generate greater licensing fees than the cost of filing, prosecuting and maintaining the patent application/patent). Thus, the decision of which inventions to protect by way of a patent application is a balance between legal and commercial considerations of the Universities and academic/research institutions, in which the researchers may have little say.

Question 3. Have any of your selected research topics led to students researching and/or exploiting active/lapsed/expired patents?

The majority of responders stated that none (18% Yes, 65% No, and 17% never selected a research topic for students) of their selected research topics led to students researching and/or exploiting active/lapsed/expired patents.

Question 4. Have you ever read patents in the course of your work?

The results of Question 4 indicate that the majority (76% Yes) of responders have read patents in the course of their work. However, notwithstanding the majority result, we note the dissenting opinion in Supporting Information Appendix B (Table IV) "One would be much better off reading the scientific literature instead of patents to stimulate new technical solutions" and "…not interesting from a scientific point of view…" We further note the contrast between the results of Questions 3 and 4. These suggest that while researchers read patents/patent applications in the course of their own work, in the main, they do not believe their students do the same in relation to their selected research topics. This observation feeds into our second hypothesis, namely that studying relevant active/lapsed/expired patent documents could provide stimulating input for ongoing academic research. It further demonstrates the need for university programs to ignite more interest among students in the exploration and use of the potential research information contained in active/lapsed/expired patents. A patent application is typically published within 18 months of filing. This is often considerably faster than the time to publish an academic paper from the relevant research. In other words, patent applications are often a source of detailed technical information regarding new technologies that have not yet been subject to academic publication. Similarly, depending on the speed of development of a particular technology area, the technical content of older patent applications/patents may still be useful to current research in the relevant area.

In connection with this, we also note the comment in Supporting Information Appendix B (Table IV): "Patents are inherently hard to read unless one is skilled in the art. By looking at only lapsed or expired patents one misses the larger picture and those not skilled in the art can miss the weak points or methods. better to see the whole picture with a guide skilled in the art." Thus, we would recommend that students and researchers are taught how to read patent documents and how to maximize their return on this effort, by identifying and focussing their attention on those parts of a patent document that are most likely to contain useful technical information.

Question 5. Do you think that the introduction of basic Intellectual Property (IP) modules to STEM course curriculum would enhance novel/innovative outcomes in research?

This question builds on the analysis above. Nearly half of the responders thought that the introduction of basic IP modules to STEM course curriculum would enhance novel/innovative outcomes in research (47% Yes, 13% No, and 40% Don't know). Indeed, one commentary in Supporting Information Appendix B (Table V) indicates that the IP training has benefits beyond that of stimulating research outcomes "I see the potential about making students aware of the benefits and pitfalls of IP when developing new technologies and solutions." This is further emphasized in another commentary which states that "having student understand how to create innovative ideas and work with the patent system is a useful and valuable skill." These results support our first hypothesis, namely that the introduction of basic IP courses to university STEM curricula would teach students valuable basics of IP and associated issues, technology protection and possibly stimulate novel/innovative R&D outcomes.

Nevertheless, we note mixed views as to the stage at which IP training should be provided. For example, one opinion in Supporting Information Appendix B (Table V) distinguishes between the content of undergraduate and postgraduate/graduate curricula and states "….I do not see a need for patents related lectures in under graduate curriculum. For graduate students starting their thesis work it can be a very useful idea to introduce some lectures on this aspect." However, another opinion does not make this distinction and states "Patents innovation process should be more familiar to undergraduate and graduate students." In connection with this, we note that research is not solely performed by postgraduates or in graduate school. Indeed, this point is raised in another commentary which states "You have been unnecessarily restrictive in mentioning research students, as though all innovation comes from universities." For example, we note that many high-tech start-up companies are founded by the newly graduated, who as noted above, would benefit from some exposure to patents/patent applications in establishing the technology pipelines for their new initiatives.

In a corresponding fashion to the previously mentioned regarding the difficulties in reading patents, we note the comment in Supporting Information Appendix B (Table V) that "trying to learn from patents without a deep understanding of how the patent system works simply fools the researchers." However, this comment appears to be more closely aligned with the issue of studying patent documents (to obtain stimulating input for ongoing academic research) rather than the broader topic of introducing basic IP modules into STEM curricula.

There are many different reasons for reading patents/patent applications documents (e.g., to secure patent protection for an invention, to establish legal and commercial aspects of the scope of protection etc.). We have discussed above (in our analysis of the answers to Question 4) the benefits of studying patents/patent applications to provide stimulating input for ongoing academic research. However, the aim of securing patent protection appears in the following comment in Supporting Information Appendix B (Table V): "….I do not personally think that studies of this kind have significant influence on the direction of most student research projects. They may predispose students to think about patenting their project outcomes, where relevant, but the drive to do this usually comes from the supervisor/advisor….." The range of perspectives about the purpose of patents/IP training demonstrates the importance of including as part of any such training a clear articulation of the specific purpose of the relevant IP training activity; and the close alignment of the content and focus of the training activity with the articulated purpose.

Question 6. Do you think that studying active/lapsed/expired patents would stimulate novel/innovative outcomes in research?

Similar reflections to those discussed in connection with Question 5 may be applicable to the results from Question 6 as the opinions of the responders indicate that 45% think that studying active/lapsed/expired patents would stimulate novel/innovative outcomes in research (45% Yes, 6% No, and 49% Don't know).

Question 7. Would you have any ethical issues with exploiting lapsed/expired patents for your benefit?

The minority 15% of the responders said Yes (51% No, 34% Don't know). It should be noted that by allowing a patent/patent application to lapse, the patent/patent application owner has effectively abandoned the monopoly rights/potential monopoly rights conferred by the patent/patent application, thereby allowing others to make use of the claimed invention. Thus, the received responses to this question could be partly the result of the responders' knowledge of patent law.

Question 8. Do you think exploiting lapsed/expired patents has benefits from a competitive or economic standpoint?

The majority 59% of responders to this question were unaware of the commercial benefits of exploiting lapsed/expired patents (31% Yes, 10% No, and 59% Don't know). High levels of uncertainty were also expressed in the answers to Questions 9 and 10 (respectively, 45% and 45% Don't know).

Question 9. Do you think anyone trying to innovate in the Open-source space will see patents as restrictive?

42% agree, while 13% disagree and 45% responded "Don't know."

Question 10. Do you think the patent system is broken?

The opinions of the 375 responders in the optional Question 10 indicate that 36% do not think that the patent system is broken (19% Yes, 36% No, 45% Don't know). However, it should be noted that this is an international survey and patent systems differ by country. Notwithstanding these results, the survey commentary accompanying the question responses (in Supporting Information Appendix B, Table X) raise several criticisms about patent law and patent systems in general. More specifically, concerns were raised about:

1. Patent system protects large companies not individual inventors
2. Frequency and scale of maintenance fees are field independent
3. Scale of protection is field independent
4. Duration of the patent term
5. Poor quality patent examination (e.g., leading to patents being granted that lack novelty)
6. Poor quality patent specifications (i.e., unclear invention descriptions and claims
7. Long, cumbersome and expensive process

4.2.1 | Technology-based patent policy tailoring

A recurring theme among the comments is the necessity of tailoring of IP incentives to different technological domains. The current patent system applies a uniform set of rules to all inventions and does not discriminate by technology or industry. These rules determine whether inventions are patentable, and awards all inventions a fixed term of protection. Technology-specific patent laws are notoriously difficult to implement because the boundaries between technologies are highly ambiguous and tend to shift rapidly as technology changes. This makes it hard to categorize inventions properly. Furthermore, many inventions fall within multiple distinct categories of technology, take for example, brain-computer interface technology, which could be considered as a software, computer hardware/electronics, medical devices, or diagnostics technology.

Notwithstanding the taxonomic difficulties in classifying technology types, from a practical perspective it is recognized that the time-to-market for new inventions varies tremendously across industries and technologies. For example, the average development cycle for new inventions is under a year, in the consumer products, software components sectors. The average time-to-market for a medical diagnostic test (i.e., the laboratory technologies used to perform the diagnostic) is 1–2 years (although it may take many years of additional validation testing). By contrast, the average time-to market for radiopharmaceutical diagnostics is seven to 9 years, while new drugs take

12–16 years on average to reach the market, depending on the therapeutic class. Thus, depending on a relevant technology/business sector, a technology (or the production technology therefore) may not be sufficiently developed to enable an invention based on the technology to be commercialized during the lifetime of a patent. By the same token, in rapidly developing technology sectors an overly broad patent can later become a disadvantage to patentees.

Economists have often characterized patents by their length, breadth and height (Langinier & Moschini, 2002). The length of a patent is its duration (e.g., 20-years in the United States and the UK). The breadth of a patent relates to the range of products encompassed by the claims of the patent. In general, the less specific the claims of the patent are, the broader the patent. The breadth of a patent confers protection against imitators. By contrast, the height of a patent, confers protection against improvements or applications that are that are too close to the patented innovation or are too easy or trivial. Unlike patent length, which is established by statute, patent breadth essentially depends on the claims put forth by the patentee. Thus, for policy makers patent duration is an attractive lever for tailoring patent awards.

In some of the earliest economic analysis of patent term, Nordhaus (1972) found that there was little effect on welfare from extending patent terms beyond 10 years. Scherer (1972) believed in a flexible, product-specific patent term system and noted that a good policy “would tailor the life of each patent to the economic characteristics of its underlying invention.” Klemperer (1990) suggested that “optimal patent policies vary across different classes of products.” Similarly, Thurow (1997) proposed a patent system which considered the technology and income of the country, the industry and the type of knowledge. O'Donohue et al. (1998) combined patent breadth and patent life into a single variable, namely the effective patent life. This represents the expected time until a patented product is replaced in the market. They noted that the discrepancy between effective and statutory patent lives vanishes if patents are very broad, so that every subsequent innovation in a product line infringes every unexpired patent in the product line (O'Donohue et al., 1998)

Proponents of tailoring identified a range of factors for use in tailoring patent awards, including: R&D costs, technological risk, public funding for the research, value of patent disclosures, cumulativeness of innovation, transaction costs, network effects, due diligence costs related to patent searches, problems related to patent leveraging and misuse, and other abuse problems. For example, Roin argued that an ideal patent award for an invention is a function of four factors, namely its R&D costs, the risk of failure, the anticipated future revenue streams from the project, and the potential for imitation by rivals; wherein time-to-market is a reliable indicia of these four factors (Roin, 2014). The difficulty lies in combining all of these variables (some of which run counter to each other) into an administrable system for tailoring patent awards. To date there has not been a concrete alternative to the existing domestic patent term system (Lester & Zhu, 2019). In an effort to address this, it has been suggested that technology-specific tailoring of incentives need not be limited to statutory change, and could instead use other mechanisms (Pammolli & Rossi, 2005) including antitrust intervention and proactive policies aimed at inducing cross-licensing and the formation of patent pools; research exemptions, the stringency of PTO examinations, government subsidies, or even prizes.

4.2.2 | Quality

Another recurring theme among the comments relates to the quality of granted patents and the patent examination process. Khanna notes that the understood meaning of patent quality varies between the different stakeholders in the patent system and the context within which the patent is being used. For instance:

1. A patent attorney or a patent office will view the topic through a legal lens wherein a high-quality patent is one that fulfils the statutory patentability conditions;

2. An engineer/scientist may view the topic through a technology advancement lens, wherein a high-quality patent is one which protects a major technological advancement rather than an incremental improvement;
3. A patent owner may view a high-quality patent as one which prevents competitors from grabbing market-share; and
4. An economist may view a high-quality patent as one which provides incentivisation for an invention that would not otherwise have been made (Khanna, 2019).

In an effort to provide a more objective approach, the academic literature has identified a number of variables pertinent to patent quality. However, in an analogous fashion to the discussions of technology-based tailoring of patent coverage, the academic analysis has not yet produced a concrete administrable system for regulating patent quality.

4.2.3 | Patent pendency

A further comment related to the length of the patent process. In sectors with rapidly developing technologies, a technology (or an aspect thereof) may be obsolete by the time a patent is granted for it. In some countries, the average time to grant from application now stands at 10 years or more. As noted by Schultz and Madigan, in Thailand, the average pharmaceutical patent granted in 2015 was 16 years old. In Brazil, patents in mobile technology fields are averaging more than 14 years old. The issue of lengthy pendency times for patent applications is not confined to cutting edge industries, nor is it confined to a particular discipline domain. For example, both mobile technology and the life sciences suffer from high average pendency periods in Brazil, Thailand, and other countries (Schultz & Madigan, 2016).

Increased pendency (i.e., elapsed time between the filing of a patent application and issuance of a grant decision), leads to a longer period of uncertainty in which the scope of granted patent rights is unknown. During this time, businesses may be unable to bring products to market, on account of difficulties licensing their invention or obtaining investment (e.g., venture capital) to further develop and market their invention. For a pending patent rights are not effectively enforceable and with that the inventor is less protected from imitators. A study found that for each year of delay in reviewing a firm's first patent application that is eventually approved, reduces the firm's employment and sales growth over the 5 years following approval by 21 and 28 percentage points, respectively. Indeed, a 2-year delay has the same negative impact on a startup's growth and success as outright rejection of the patent application (Farre-Mensa, Hegde, & Ljungqvist, 2016).

Treating the speed of technological progress as a constant depreciation factor on the private value of a patent over time, faster discovery of new and superior technical knowledge is represented as a higher degree of depreciation and shorter value horizon of the patent. Thus, firms will have a stronger incentive to secure early patent grants if new technologies are emerging at a faster rate. Indeed, a firms' propensity of choosing a fast patent increases as the relevant technology area develops faster (Cao, Lei, & Wright, 2014). Thus, speed of patent grant is a potential policy lever in which patent applicants might be willing to secure a fast patent at the expense of protection length and enforcement strength.

4.3 | Limitations of the survey

Possible sources of bias which may have influenced the outcome of the survey are as follows. As previously mentioned, the profile responses (Appendix A.1**:** Table VII) demonstrate a skew in the survey population towards academia. However, a significant proportion of research is undertaken in industry without academic involvement (as mentioned in the comment in Supporting Information Appendix B, Table V). According to the World Intellectual

Property Office (WIPO, 2019), in 2018 China received 46.4% of all patent applications filed worldwide. However, Table IX (in Appendix A.1) indicates that there was a relatively low participation of responders from China in the present survey (15 responders = only 3%).

The survey was primarily conducted in the field of electrical engineering, that is, IEEE technical Society members are the survey responders. Thus, few, if any, researchers from other STEM disciplines were included in the survey.

Similarly, the total number of responders to the survey (only 522 out of a population of 51,213) could be considered low. A number of potentially contributory factors have been identified, including the following:

1. The e-newsletter with a link to complete the survey; mentioning the topic of patents, may have lowered the participation rate by members who do not work in relevant areas;
2. Language barrier for many of the IEEE members (survey was only provided in English);
3. Survey may have appealed more to academics;
4. The IEEE Societies' e-newsletters contained other announcements/items of interest which attracted the attention of members more than the survey announcement; or
5. The e-newsletters were ignored/never opened by the IEEE members.

While the survey was designed to avoid leading questions, we note that a slight bias may have arisen from the definitions and information (see Sections 2.1 and 2.2) relayed to the responders. Nevertheless, the large number of voluntary details (e.g., over 80 comments related to Question 1 alone: see Table 1 in Supporting Information Appendix B), and comments with mixed views, indicate that many responders were very engaged with the survey and willing to provide their uninfluenced responses. In the case of Questions 1, 2, and 3, we can observe that 87, 88, and 89 responders, respectively, state that they have never selected a research topic for students, which represents an inconsistent response error margin of ±1 (but with each result rounding off to 17%).

5 | FUTURE WORK

We note the potential for friction between the aims and perspectives of the different members (e.g., academic leaders, policy makers, and funding bodies) of our audience. Governments may focus on patenting as a stimulus for innovation thereby generating sustainable economic growth. By contrast, academic leaders may resist interference of commercial agendas in academic freedom and institutional autonomy, unless it can be demonstrated that the inclusion of IP training in a STEM curriculum fulfills a pedagogic purpose and/or increases research activity. Thus, further studies regarding the inclusion of IP training into academic training should overtly address these points. However, an overly legalistic focus on the minutiae of patent law could be counterproductive.

The high percentage of “Don't know” responses to Questions 5 and 6 are worth exploring further. Respectively, the 40% and 49% of the surveyed population, who apparently do not know whether IP training or studying patents would improve research outputs. This potentially reflects a lack of understanding of IP by the survey responders, or a conscious ambivalence to IP training or studying patents. Although, the reasons may also be more complex and/or nuanced. This needs to be further explored especially since the same set of respondents (in Question 4) said that they read patents during the course of the work (majority 76%). For example, further surveys can explore whether responders have taken IP courses, or if their department runs IP courses, to unravel the reasoning behind the “don't know” responses in this current survey.

While the results of Question 4 indicate that the majority [76%] of responders have read patents during the course of their work, it is important to further explore the purpose/motivation behind such reading. In our experience, researchers typically focus their attention on journal publications relevant to their field; and rarely discuss plans to view all relevant patents. However, as Asche states “the rising number of patent (applications) shows their growing importance as an information source" (Asche, 2017). Furthermore, many research funding programs require funding proposals to include a thorough analysis of existing technologies/products/services/patents and discussions about how the public monies invested in the research will lead to economic (and/or social or other) benefits. However, bearing in the dual legal and technical aspects of a patent/patent application, we recognize that patent literature can be challenging to read (a criticism also raised by some of the responders in Table IV from Supporting Information Appendix B). However, the purpose of reading patent documents is not confined to informing future research projects or funding proposals. Thus, a more detailed exploration of the motivations behind the results to Question 4 is an important piece of future work.

Finally, we note that the survey was primarily conducted in the field of electrical engineering, that is, IEEE technical Society members are the survey responders. Therefore, future surveys should include respondents from other fields, such as the chemical and life-sciences.

6 | CONCLUSION

The present survey demonstrates a distinct appetite within the researcher community for the inclusion of basic IP courses to university STEM curricula, which would teach students valuable basics of IP and associated issues, technology protection and possibly stimulate novel/innovative R&D outcomes. The survey results also suggest that while researchers read patents/patent applications in the course of their own work, in the main, they do not believe their students do the same in relation to their selected research topics. Indeed, nearly half the respondents indicated that they believe the introduction of basic IP modules to STEM course curriculum would enhance novel/innovative outcomes in research leading to development. We contend that the inclusion of patent training in STEM bachelor and graduate degree curricula, could ignite interest in the use of the potential research information residing in active/lapsed/expired patents to better inform their own research interests and support the preparation of more compelling grant applications and thereby secure increased institutional and personal research funding.

We further note that many of the criticisms of the patent system raised by the survey respondents align closely with several very active areas of ongoing debate and research within the legal and economics communities; and would hope to see greater participation of STEM researchers in those debates.

However, we also note the barriers to patent awareness and engagement in the researcher community, including lack of incentivization for academic researchers to submit invention disclosures for patenting; and the difficulties in reading and interpreting patent documents. In connection with this, we also recognize that there may be multiple reasons for researchers to read patents/patent applications. Thus, we would recommend that students and researchers are taught how to read patent documents, but that any such training should include a clear articulation of the purpose of the training coupled with a close alignment of the content and focus of the training with the articulated purpose.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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APPENDIX A: SURVEY RESULTS

A.1 Profile of survey responders

I. Age	Total	%
18–24 years	11	2
25–34 years	51	10
35–44 years	103	20
45–54 years	137	26
55–64 years	130	25
Age 65 or older	90	17
	522	100
II. Gender	**Total**	**%**
Male	441	84
Female	81	16
	522	100
III. Type of your affiliated organisation:	**Total**	**%**
University/College	382	73
Independent Research Institution/Center (e.g., Max Planck Institute)	33	6
Institute of Technology (IT)	29	6
Online/Distance Learning Higher Education Entity	2	<1
Other	76	15
	522	100
IV. Have you ever supervised a thesis/ dissertation?	**Total**	**%**
Yes	368	70
No	154	30
	522	100
V. Have you ever served on a doctoral committee?	**Total**	**%**
Yes	273	52
No	249	48
	522	100
VI. Highest level of education	**Total**	**%**
Doctorate (Ph.D.)	383	73
Master's degree	65	12
Professional (e.g., M.D., J.D., D.V.M.)	6	1

VII. Highest level of experience in Higher Education research or teaching:	Total	100 %
Full Professor	135	26
Assistant Professor	50	10
Associate Professor	85	16
Doctorate (e.g., your Ph.D. thesis, Research or Teaching Assistant)	44	8
Graduate (e.g., your Master's thesis, Research or Teaching Assistant)	38	7
Adjunct Professor/Lecturer/Instructor	28	5
Lecturer/Instructor	28	5
Postdoc (Research Fellow or Associate, Research or Teaching Assistant)	22	4
Senior Lecturer/Instructor	19	4
Undergrad (e.g., your Bachelors thesis, Research or Teaching Assistant)	15	3
Distinguished Professor or Endowed Chair	13	2
Professor Emeritus/Emerita	11	2
Research Technician	6	1
Honorary Professor	4	1
Clinical Professor or Professor of Practice	3	1
I don't have any experience in Higher Education research or teaching	21	4
	522	100

VIII. Choose a field that best describes your "research/role":	Total	%
Engineering	202	39
Engineering technologies and engineering-related fields	178	34
Computer and information sciences and support services	75	14
Physical sciences (e.g., Physics, Astronomy, Chemistry, Earth)	26	5
Biological and biomedical sciences	13	2
Mathematics and statistics	12	2
Business management, marketing, and related support services	7	1
Agriculture, agriculture operations, and related sciences	1	<1
Health professions and related programs	1	<1
Not STEM related	7	1
	522	100

IX. Choose the country of your affiliated organization:	Total	%
United States	177	34
Spain	41	8
India	31	6
Germany	22	4
Australia	17	3
Canada	15	3
China	15	3
Italy	14	3
Japan	12	2
United Kingdom	11	2
Mexico	10	2
Other countries	<10	30
Countries with less than 10 responders are not shown in this table	522	100

A.2. Survey questions

I: Q 1. What is your greater expectation when selecting research topics for students?	Total	%
I expect students to develop new research skills	193	37
I expect students to pursue novel/innovative outcomes	242	46
I have never selected a research topic for students	87	17
	522	100

II: Q 2. Have any of your selected research topics led to students filing for patent protection?	Total	%
Yes	134	26
No	300	57
I have never selected a research topic for students	88	17
	522	100

III: Q 3. Have any of your selected research topics led to students researching and/or exploiting active/lapsed/expired patents?	Total	%
Yes	95	18
No	338	65
I have never selected a research topic for students.	89	17
	522	100

IV: Q 4. Have you ever read patents in the course of your work?	Total	%
Yes	396	76
No	126	24
	522	100

V: Q 5. Do you think that the introduction of basic Intellectual Property (IP) modules to STEM course curriculum would enhance novel/innovative outcomes in research?	Total	%
Yes	245	47
No	69	13
Don't know	208	40
	522	100

VI: Q 6. Do you think that studying active/lapsed/expired patents would stimulate novel/innovative outcomes in research?	Total	%
Yes	234	45
No	30	6
Don't know	258	49
	522	100

VII: Q 7. Would you have any ethical issues with exploiting lapsed/expired patents for your benefit?	Total	%
Yes	80	15
No	266	51
Don't know	176	34
	522	100

VIII: Q 8. Do you think exploiting lapsed/expired patents has benefits from a competitive or economic standpoint?	Total	%
Yes	164	31
No	51	10
Don't know	307	59
	522	100

IX: Q 9. Do you think anyone trying to innovate in the Open-source space will see patents as restrictive?	Total	%
Yes	220	42
No	67	13
Don't know	235	45
	522	100

X: Q 10. Do you think the patent system is broken?	Total	%
Yes	71	19
No	136	36
Don't know	168	45
(Voluntary responders)	375	100