J Technol Transf
DOI 10.1007/s10961-017-9613-9

Scientific and technological (human) social capital formation and Industry–University Cooperative Research Centers: a quasi-experimental evaluation of graduate student outcomes

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Abstract In the current paper, we attempt to contribute to a more comprehensive understanding of science, technology and innovation (STI) outputs and outcomes through the application of a Scientific and Technical Human Capital (STHC) evaluation framework. We do this by describing a study that focuses on a type of STI initiative that appears ripe with potential to affect STHC impacts—Industry–University Cooperative Research Centers (IUCRCs). In doing so we summarize relevant theory related to the STHC framework and social capital formation more generally. We also define IUCRCs and highlight the program mechanisms that appear likely to impact the STHC outcomes. Finally, we narrow our focus to a relatively neglected research target of the STI evaluation—science and engineering (S&E) doctoral students. We compare social capital and other students' outcomes by employing a rare quasi-experimental design with two training modalities: IUCRC and more traditional, non-center training. We show that our results demonstrate strong evidence for positive effects of IUCRC training on graduate S&E students' outcomes. We also explain significant moderating effect of citizenship status on some of our results where international students, who account for 50% of this population, do not receive the same social capital outcomes as students with US citizenship or permanent resident status. In addition, we describe patterns in international students' intentions to stay in the US and how they are affected by students' training modality. Finally, we discuss the results and implications in the context of graduate training, STHC evaluation framework and STI and immigration policy.

Keywords Social capital · Students · Science technology and innovation · Cooperative research centers · Industry–university cooperation

JEL Classification J24 · O15 · O34

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Published online: 16 August 2017

1 Introduction

There is a broad and growing consensus within the science, technology and innovation (STI) and technology transfer policy and evaluation communities on the need to both advance and diversify our methodologies and metrics. For instance, over the past several years National Science Foundation's (NSF) Science of Science and Innovation Policy program, which aims to "advance the scientific basis of science and innovation policy", has taken a leadership position in encouraging the advancement of traditional STI methodologies. Notable examples include continuing support for the *Science and Technology for America's Reinvestment: Measuring the Effects of Research on Innovation, Competiveness and Science* (STAR Metrics) project which attempts to create a repository of data and tools that will be useful to assess federal R&D investments (Lane and Bertuzzi 2011; Largent and Lane 2012). Similar efforts are underway globally, headlined by the annual Valencia-based International Conference on Science and Technology Indicators (See: http://www.sti2016.org/). At the same time, STI evaluation scholars have also pointed out the need for addressing important but neglected outcomes (Bozeman et al. 2015; Magro and Wilson 2013).

In our opinion, progress in achieving these two goals within the STI community has been somewhat mixed. On the one hand, a great deal of progress has been achieved in enhancing relatively mainstream microeconomic and bibliometric measures (including "altmetrics) that the field has heavily relied on for decades (Priem et al. 2010, 2012). For instance, the STAR Metrics program and related efforts abroad have been very effective in stimulating this kind of research and have led to a number of valuable articles (e.g., Bertuzzi and Jamaleddine 2016; Bouabid 2014; Murray et al. 2012) and compilations (Link and Vonortas 2013). On the other hand, in our opinion, much less progress has been made in conducting studies and developing the methodologies that address more complex but just as important STI outcomes, most notably Scientific and Technological Human Capital (STHC). This is a potentially important capacity building STI outcome highlighted by Bozeman and his colleagues over 15 years ago (Bozeman et al. 2001). Given the potential STHC impacts can have on the innovation process, we consider this a major failing.

While Bozeman and his colleagues highlighted some of the reasons scholars have neglected STHC in their landmark paper (Bozeman et al. 2001), we suspect this continuing state-of-affairs is due to a number of factors including:

- While most STI or technology transfer initiatives are typically designed to promote relatively discrete scientific and/or economic impacts, only a subset are designed to impact STHC kinds of impacts.
- STHC effects are challenging to detect because they often involve relations with the external environment and diverse organizations, and they have a long latency which makes them even more difficult to capture.
- While the theoretical foundations undergirding our understanding of social capital is very broad, it is also diffuse and little progress has been made on STHC-specific measurement development.

The current paper will attempt to address some of these impediments/concerns and contribute to a more comprehensive understanding of the challenges associated with the STHC-based measures and general application of a STHC-based evaluation framework. We will do this by presenting the methodology and results of an empirical study that focuses on a type of STI initiative that appears ripe with potential to affect STHC impacts—Cooperative Research Centers (CRCs)—and one of its main stakeholders—

graduate students. In doing so we will first summarize relevant theory related to the STHC framework and to social capital formation more generally. Next, we will define CRCs and specify the program mechanisms that appear likely to impact the STHC outcomes. In doing so we will also highlight a relatively neglected research target for such impacts—CRC-trained graduate students. Finally, we will present hypotheses based on this background and the context of the outlined challenges facing the current STI metrics, describe our methodology and report our results.

2 Scientific and Technical Human Capital (STHC) framework for STI evaluation

It is important to understand that embracing the STHC framework represents a broadening of existing STI evaluation approaches not a replacement of traditional frameworks. The objective of existing evaluation approaches has typically been to measure the discrete outputs or outcomes of research and development (R&D) rather than its more dynamic processes. These methods stem from neoclassical economics where the value of scientific research is measured by discrete "hard" outputs in the form of publications, patents, jobs created or technology transfer events (Griliches 1958). The role of these outputs have not diminished over time; they have continued to play a central role in the most commonly used benchmarking surveys such as the European Union's Community Innovation Survey and the Business R&D and Innovation Survey (Jankowski 2012; Hall 2011). Moreover, these hard outcomes are applied to evaluate STI across sectors: from small R&D firms (Arvanitis 2012) to large public institutions such as National Institute for Science and Technology (Link and Scott 2012). Although "disembodied from the individuals and social context" where these output have been produced, these "static" and "product-oriented" approaches are familiar to policy makers and to the media and there has been little incentive for change (Bozeman et al. 2001, p. 718). Unfortunately, important externalities of the scientific process are not being captured by these methods. In contrast, evaluation strategies that assume we are assessing system-based effects that include important endogenous processes, argue that we need to move beyond simple "A → B" evaluation paradigms and take into account input, output and behavioral "additionalities" of our interventions (Arnold 2004). Thus, there is a need to diversify our assessment strategies by focusing more on the scientific process rather than mere outputs.

More concretely, the STHC approach targets "the sum total of personal skills, knowledge, and the social resources scientists and engineers bring to, and develop from, their work" (Gaughan and Ponomariov 2008). At the heart of the STHC perspective is the belief that if we look beyond scientific outputs, we will notice that investments in science can generate important scientific and innovation capacity impacts (Ponomariov and Boardman 2010). Such impacts are not limited or frozen in time; they can cross individual or project boundaries and enhance the institutional and national capacity to develop and innovate. Under this perspective, there lies "the socially-embedded nature of knowledge creation … and the dynamic, capacity-generating interchange between human and social capital" (Bozeman et al. 2001). An extreme example is the scientific and social interplay where scientists, industry R&D, manufacturers and the like form "knowledge value collectives"—large social networks shaped by shared knowledge or a common problem (Bozeman and Rogers 2001). Thus, from the STHC standpoint, some STI initiatives may add value by increasing our overall capacity to innovate and develop.

As noted above, there are two distinctive components within this definition: human capital and social capital. Human capital represents a more direct measure of an individual's education and professional experience in its traditional sense. Similar to most common types of capital, human capital is static, especially among researchers, most of whom hold or are on the way to receiving their doctoral degrees. Some go even further arguing that "there is no variation … in education attainment, among scientists" (Allen and Katz 1992, p. 38).[1]

In contrast, "social capital is not a single entity but a variety of different social phenomena that possess some aspect of structural relations which facilitates actions of individuals or groups" (Bozeman et al. 2001). Social capital is also dynamic and can increase or decrease by virtue of a particular scientific interaction. At its heart social capital is about social networks and their exploitation. According to Bozeman and colleagues:

> …we conceptualize social capital as the cooperative glue that binds collaborators together in knowledge exchange … exploit the complementary assets of scientists, mentors, students, administrators and key community figures who work together toward an agreed upon and mutually beneficial end.

This is not to say that human capital and social capital are independent. Within the STHC framework, social capital represents the social channels (social networks) through which human capital can be shared with others. Importantly, an analysis of social capital is also applicable to different levels of analysis: individual, project or product, program, scientific field and knowledge value collectives or combinations (Bozeman et al. 2001). With each higher level, however, it becomes more difficult to measure.

Since the social capital component of the STHC is not as well understood as human capital it will be the focus of our study. Further, while we will look at a specific organizational context—cooperative research centers—we will measure social capital at the individual level. The next section provides a brief review of theoretical and empirical background and measurement strategy on the subject.

2.1 Social capital theory and measurement

Social capital finds its roots in theories of contagion. The theory's main assumption is that social networks are "contagious" with information, attitudes and beliefs from others in the same network (Contractor and Eisenberg 1990; Carley and Kaufer 1993). Social capital's main distinction from other forms of capital is in that it "exists in the structure of relations" (Coleman 1988, p. 98) and, thus, it cannot be "owned" in the same way as other types of capital. Although there has been a great deal of interest in and theory development related to social capital across multiple disciplines (Robinson et al. 2002), a number of factors appear to have hampered the translation of this work into productive research practice.

First, the construct of social capital can be conceptualized at very different levels of analysis leading to its application to such widely divergent fields and topics as: individual financial stability (Agarwal et al. 2001; Mayoux 2001), general health and well-being (Poortinga 2012; Rojas and Carlson 2006; Rose 2000), entrepreneurial success (Davidsson and Honig 2003; De Carolis and Saparito 2006; Fornoni et al. 2010) and the World Bank's

[1] Bozeman et al. (2001) would probably take exception with this assertion since they offer a more inclusive definition of human capital that includes "tacit knowledge, craft knowledge and know-how."

social capital initiative to aid economic development in the third world countries (Grootaert and Bastelaer 2001; Woolcock and Narayan 2000).

Second, while in most instances, social capital is referred to as an informal network of family and friends an individual can rely upon, in more specific instances such as entrepreneurial social capital, it is defined through its function—social connections that help entrepreneurs to address specific problems their business is facing (Davidsson and Honig 2003). Thus, social capital can be considered as general social capital or specific construct, tailored to a particular type of social or professional activity. Finally, there is no single commonly accepted definition of the term. As community psychologists Perkins et al. (2002) noted: “The reason social capital is ambiguous and controversial is that it has been defined differently to suit different ends, or left undefined.” These factors have contributed to the creation of a complex multidisciplinary mosaic of theory and empirical literature with few common measures and referent points.

Against this somewhat confusing background we believe the most useful conceptual framework for understanding social capital has been developed by Coleman, who drew on his work on social and cognitive development (Coleman 1988) and Lin (1999), who was interested in understanding social support processes and developed a *Network Theory of Social Capital* (Lin 1999; Lin et al. 2001). In this vein, we adopt Lin’s definition of social capital as: “resources embedded in a social structure which are accessed and/or mobilized in purposive actions” (Lin 1999, p. 35). By social structure he means the network of social connections. He explains that there are three major components of social capital: “resources embedded in a social structure; accessibility of such social resources by individuals; and use or mobilization of such social resources by individuals in purposive actions.” Lin claims that “social capital, as a concept, is rooted in social networks and social relations, and must be measured relative to its root” (p. 35). As a consequence, researchers would typically reference a target’s social network (e.g., size, strength, diversity) to assess each of these elements. In a network, accessibility is represented as structural position of a person in a network and/or the type of connection one has with others. For examples, multiple scholars agree that the network connection (tie) can be characterized as weak or strong (Granovetter 1983; Levin and Cross 2004). It is believed that both types of these connections serve different purpose. Weak connections are not weak in traditional sense; they can represent connections one may make at a professional or academic conference that can result in future collaborations.

While social network analyses can capture *resource* and *accessibility* components of social capital, they do not address the factors that help one *mobilize* these network resources. Mobilization is a somewhat abstract concept. According to Lin it relates to trust, norms and values other scholars mention when defining social capital (Lin 1999). In his definition, one important part of social capital is mobilization of resources embedded in one’s network in “purposeful actions” (Lin 1999, p. 35). Thus, availability of mutual trust and shared norms can serve as a facilitator or mediator of mobilization as it increases the likelihood that an individual will mobilize those resources. This dimension of social capital again reminds us of glue that brings all the resources in one’s network together to be acted upon. Trust and shared values usually bring confidence in one’s position and encourage individuals to act.

While Coleman and Lin provide a conceptual and measurement framework for the concept of individual social capital, Bozeman and his colleagues propose the theoretical STHC framework of human and social capital in the context of the technology transfer process and STI initiatives as a whole. Unfortunately, in the last 15 years, a relatively small number of studies have applied the STHC framework empirically to scientists in academia and industry (Corolleur et al. 2004; Gabbay and Zuckerman 1998; Gaughan and Robin 2004; McFadyen and Cannella 2004; Turpin et al. 2010). The typical methodology used includes a combination of publication and CV data and surveys. The studies vary from a focus on early academic scientists' career paths in France and in the US (Gaughan and Robin 2004) to market strategies of industrial researchers in biotechnology spin-off firms (Corolleur et al. 2004). Some studies do not exclusively apply the STHC framework, but they focus on social capital in science and research settings. For example, McFadyen and Cannella's (2004) study of biological research scientists' co-authorship history (as evidence of the social capital size and strength) and subsequent knowledge creation based on journal impact ratings. Another example includes Gabbay and Zuckerman's (1998) examination of the social capital of corporate scientists (as measured by social network embeddedness scores) and subsequent promotions.

In summary, the STHC evaluation approach, particularly its social capital component, provides a promising framework for the STI evaluation. One can assess STHC longitudinally before and after a particular project or a program being implemented. The method can potentially be implemented at the individual as well as group level of analysis if desired. In contrast to the static output-based metrics, STHC assessment can estimate the capacity to contribute to future scientific and technical endeavors as a result of a STI project or program. Nevertheless, the construct is relatively complicated and it is clear that multiple methodological and measurement issues need to be addressed in order to encourage more wide spread empirical assessment of this construct.

3 Cooperative research centers and social capital formation

As mentioned earlier, specific STI initiatives are more or less likely to have an impact on human and social capital outcomes. Since social capital is socially embedded (Coleman 1988, p. 98), initiatives that encourage a significant amount of collaborative activity in an organic and sustainable way are the most likely to promote social capital development. This would seem to be very much the case for one type of STI program—cooperative research centers (CRCs). Based on our prior work, a CRC is:

> an organization or unit within a larger organization that performs research and also has an explicit mission (and related activities) to promote, directly or indirectly, cross-sector collaborations, knowledge and technology transfer, and ultimately innovation. (Gray et al. 2013)

The term CRC should be considered as a general type of initiative which encompasses a variety of related labels (e.g., research center; center of excellence; strategic partnership; organized research unit) and agency specific "brands" (e.g., Engineering Research Center (ERC); Industry–University Cooperative Research Center (IUCRC); Science and Technology Center). CRCs are an important and interesting target for STI scholarship for a number of reasons: they are very common element of most nation's STI program portfolio; estimates of their prevalence in the US alone number in the thousands; they have the potential to have impacts on multiple stakeholder groups (e.g., faculty, students, large and small firms, local and national governments); assessment of their impacts on these stakeholders has consistently been very positive (Gray et al. 2013).

Given our purposes, CRCs are interesting because they appear to incorporate to a number of mechanisms that have the potential to have a significant impact on human and social capital outcomes (Gray et al. 2013). These features include:

- *Team science mechanisms* CRCs involve collaborative or team-based research which are often cross-disciplinary, multi-institutional and/or cross-national giving them the potential to affect social networks across each of these boundaries;
- *Triple helix mechanisms* CRCs by definition involve cross sector collaboration (often co-funded by government) and therefore have the potential to affect social networks across academic, private and public sector boundaries;
- *Open innovation mechanisms* Although the level of firm-to-firm interaction can vary significantly, many CRCs are consortial in nature involving multiple private and public sector organizations and have the potential to affect social networks across firms within a particular sector;
- *Human capital/training mechanisms* Many CRCs involve a graduate and post-doctoral training component and have the potential to affect social networks between students and other stakeholders at the critical point when the students are launching their scientific careers.
- *Different levels of analysis* Given their more formalized organizational structure and programmatic support CRCs have the potential to have effects at the individual, organizational, programmatic and perhaps even a "knowledge value collective" level referenced by Bozeman et al. (2001).

In spite of the fact that CRCs appear to incorporate a number of mechanisms that have the potential to affect STHC outcomes, the level of attention devoted to investigation of these outcomes does not differ substantially from the general trend in STI evaluation of employing the traditional hard microeconomic metrics. Also, in spite of a long standing evaluative interest in CRCs, only recently have scholars begun to apply the STHC framework (Boardman and Corley 2008; Bozeman and Corley 2004; Lin and Bozeman 2006; Ponomariov and Boardman 2010). Most of these studies focused on established scientists (Bozeman and Corley 2004; Dietz and Bozeman 2005; Lin and Bozeman 2006; Ponomariov and Boardman 2010) and topics concerning collaborations (Bozeman and Corley 2004) and academic careers and productivity (Dietz and Bozeman 2005).[2] For the most part, however, scholars involved in the evaluation of CRCs have not systematically examined STHC effects of these interventions.

In summary, because of the various multi-faceted collaborative processes involved in CRCs, they appear to have the potential to affect social capital of a variety of stakeholder groups. As we will point out in the next section, graduate students who are trained in these structures represent a promising but neglected target for such research.

3.1 Research on CRC student outcomes

As noted above, most CRCs include a graduate training mission and students are frequently cited as one of the CRCs most important stakeholders and outputs (Gray and Rivers 2008; Gray et al. 2011). While precise aggregate statistics are difficult to obtain, various NSF center programs (e.g., Engineering Research Centers (ERCs), Science and Technology Centers (STCs), Industry–University Cooperative Research Centers (IUCRCs), material research science and engineering centers (MRSECs) provide support for several thousand graduate students each year.[3] These students are trained in a wide spectrum of disciplines

[2] Johnson and Bozeman (2012) proposed the way to use the STHC model in helping minority students to succeed in academic medicine and science, but their approach was not empirical.

[3] For detailed information on the number of IUCRC students visit https://www.ncsu.edu/iucrc/NatReports.htm. For the detailed information on the number of ERC students see individual ERCs' reports and

and tend to mirror national populations of students in science and engineering programs with roughly half being international students and minority women (National Science Board 2016).

The extant literature on CRC graduate students has been reviewed in a working paper (Leonchuk and Gray 2017) and was surprising in a number of respects. First, given the importance attached to training of students by scholars and industry stakeholders, the size of the literature is quite modest. We could only find seven empirical studies on CRC student outcomes and impacts over a 25 year period. In addition, only two of the studies (Behrens and Gray 2001; Mendoza 2007) were published in easy-to-access peer reviewed journals while the rest are archived in technical reports designed exclusively for the program's internal needs. With a few exceptions (Behrens and Gray 2001; Schneider 2007; Scott et al. 1993), the studies were descriptive or correlational in methodology. Finally, although all of the studies find a positive or at least no negative impact of CRC training and a few mentioned enhanced "interactions" with firms, none of the studies mention and explicitly examine social capital outcomes.

3.2 International students

As noted above international students constitute a majority of doctoral students trained in the US in many science and engineering fields (National Science Board 2016). Formation of social capital is especially important for international students as they have to adapt to a new culture and often learn a new language in addition to their rigorous scientific training. This segment of the S&E population has become more important recently as there are more opportunities than ever to pursue education abroad (Kim et al. 2011; Waters 2006). Most literature on international students looks at issues related to their adaptation to a new culture (e.g. cultural shock) and their demographics and career paths.

Majority of international students' decision to come to the US is contingent on their home countries' socioeconomic conditions (Finn 2010; Roh 2015). For example, the bigger unemployment gap exists between students' country and the US the more likely students will pursue education in the US (Kim 2016; Roh 2015). These conditions vary across countries which in turn determine their rate of students coming to the US (Finn 2010). In addition to these "push" factors, students are also "pulled" to the US by the quality of its institutions (84%) and more career opportunities (74%) according 2016 Kauffman report (Han and Appelbaum 2016).[4] At the individual level, international students gain a competitive advantage over their peers who are not educated abroad (Kim 2016; Waters 2006). One of the main advantages considered in the literature are social and cultural capital (Bourdieu 2011; Kim 2016; Waters 2006) which can be enhanced or diminished by students' ability to adopt to the new culture (Ingram et al. 2013). Similar to social capital, cultural capital is considered to be critical to individual's "social reproduction" (Waters 2006).

Given importance of this highly skilled work force, different studies have tried to shed a light on the rate of foreign students staying in the US and what factors influence their decisions. According to Finn (2010), most influential are socioeconomic factors of their home countries where some countries have very high rates of S&E doctoral recipients

Footnote 3 continued
publications (Huang 2009) or websites (ERC ASSIST: https://assist.ncsu.edu/; ERC FREEDM: https://www.freedm.ncsu.edu/).

[4] The Kauffman report is based on online survey sent to current STEM graduate students at ten US universities with largest total number of enrolled international students.

staying after 5 years since graduation (China 92%, India 81%) while others much lower (Thailand and Saudi Arabia 7%). The rate also depends on quality of academic institutions at home. For example, the third largest "exporter" of students to the US, South Korea, is able to attract back most of its US doctorate recipients. For instance, only 41% of its doctorate recipients stay in the US—a much lower rate than China's and India's (Finn 2010). Another indication of this trend is that 89% of South Korean S&E faculty received their doctorates from the US (Kim and Roh 2017). While it is possible to estimate the rate of students staying based on their intentions (Han and Appelbaum 2016), the first year's employment commitment and intentions (Roh 2015)[5] or a more concrete data of tax records and social security numbers (Finn 2010), it is more challenging to explain what makes they stay. Besides socioeconomic conditions of students' home countries being strongest factors, Finn shows that students who aim to work in academia and who have strong ties with their families at home go home at higher rates (2010). However, studies like these do not take into account experiences and type of training students receive in the US. Thus, our study aims to investigate whether the center training has any effect on international students' intentions to stay in the US.

3.3 Summary

CRCs provide a rich and highly collaborative environment for multidisciplinary, cross-institution, cross-sector collaboration particularly for the large number of graduate students who are trained in these settings. As a consequence, they appear to have a high potential for producing STHC impacts. Surprising, however, very little research has examined these impacts for faculty and none, among the studies we were able to find, for students. In the next section, we develop hypotheses related to CRC impact on graduate students and describe the methodology we used to test these hypotheses.

4 Methods

The literature review demonstrates a significant potential of the STHC evaluation framework to capture benefits of the existing STI programs that were not captured previously. It also shows that CRCs, as one type of the STI intervention, represent unique testing ground for the STHC because of their complex stakeholders' composition and their consortial nature. The literature also demonstrates that doctoral students, especially, international doctoral students, while neglected in the general STI evaluation literature are one of the most promising CRC forces that can help maintain the US STI leadership and build its innovation capacity. Based on our literature review, it seems logical that the STHC evaluation framework can and should be applied not only on established scientists, but also current doctoral students as their early career development is probably the most important time for social and human capital formation (Bozeman et al. 2001). Therefore, our methodology is heavily informed by these critical factors in order to more accurately address the promising areas of the US STI capacity building. Overall, our research questions and hypotheses not only aim to contribute to the existing STI evaluation literature, but also penetrate the practical concerns of the STI programs and their evaluation.

[5] The data are based on the Survey of Doctoral Recipients' that asks recent graduates about their intentions to stay in the US and availability of a job or postdoctoral training upon graduation.

Below we detail our study methodology. First, building on our review of the literature and the need for more diverse STI metrics, we will propose several hypotheses about the effect of CRC-based training, one type of the STI programs, on graduate student social capital outcomes that are developed as a prototype of the STHC-based evaluation framework. Next we will highlight the specific CRC program that was the basis for our study—NSF Industry–University Cooperative Research Centers program—and our study sample. Finally, we will describe our STHC-based measurement development and assessment approach and our analysis strategy.

4.1 Hypotheses and research questions

We propose the following set of hypotheses and research questions. Our first hypothesis looks at the STHC-based measure of social capital of graduate students. Consistent with the literature on CRCs and the likelihood that their collaborative processes can affect social capital, the first hypothesis investigates the effect of graduate training modality on different components of students' social capital.

H_1 IUCRC students will exhibit more of the following professional social capital outcomes than traditionally trained students:

1-a: Professional social network size
1-b: Professional social network strength
1-c: Norms and values about collaborations

Although there is not sufficient research on the role of student citizenship to justify a hypothesis about social capital formation and related outcomes, international students constitute over 50% of US S&E graduate students and have historically been an important component of our STI manpower. Some prior studies of CRCs have highlighted different effects for international students (Behrens and Gray 2001). As a consequence, we pose the following research question:

Q_1 Does citizenship status moderate the relationships between the type of the graduate training and various professional social capital outcomes?

Since satisfaction has been a common outcome measure in many students' studies (Behrens and Gray 2001; Scott et al. 1993; Schneider 2007) and improved social capital should result in a superior training experience, we propose the following hypothesis and research question:

H_2 IUCRC students will have a higher level of satisfaction with their graduate training than students trained traditionally.

Q_2 Does citizenship status moderate the relationships between the type of graduate training and satisfaction?

Given the limited professional activity of doctoral students, it is hard to capture more objective and longer-term outcomes (e.g., employability) than simple satisfaction with their training. Nevertheless, we anticipate that students at the doctoral level are well-informed about the expectations for their professions and skills required to find a job after graduation. Thus, the final hypothesis focuses on the student perception about their professional readiness in comparison with their peers:

H_3 IUCRC students will have a higher level of perceived career preparedness than students trained more traditionally.

Q_3 Does citizenship status moderate the relationships between the type of graduate training and perceived career preparedness?

The last question focuses on international students only. Given that such a large proportion of the S&E graduate students are international and given potentially important implications for the US high skilled immigration, we investigate whether the training modality has any effect on students' intentions remain in the US immediately after graduation:

Q_4 Does the type of graduate training affect plans of international students on whether to stay in the US or go home to their native country?

4.2 Training modality: IUCRC program

As we have pointed out above, there can be a tremendous amount of diversity among centers within the general type—CRCs. The specific CRC examined in this study was the National Science Foundation's Industry–University Cooperative Research Centers program. A detailed description of the IUCRC program and its unique improvement-oriented evaluation which involves data collection by on-site evaluators is beyond the scope of this paper but can be found elsewhere (Gray and Walters 1998; Gray 2008). However, given the purpose of this study, it is important to know certain parameters related to the program's operations, funding and size.

IUCRCs have been supported by NSF for over 35 years and are implemented as a fairly routinized organizational and operational model. IUCRCs are university-based, multidisciplinary centers that are supported by consortia of member firms. University faculty and students perform research that has been recommended by an Industrial Advisory Board and meet face-to-face twice each year to review progress and decide on new projects. Since NSF provides a relatively small amount of funding (average $150k/center/year) centers rely primarily on industry support. Currently there are about 65 operating centers. The average center has $1.5 million in research funds, includes three different universities, seventeen industry members, fourteen faculty (Gray et al. 2016). Centers are primarily in engineering fields but include some in science, management, and agriculture. When comparing IUCRCs to some other well-known CRCs funded by NSF including NSF Engineering Research Centers and Science and Technology Centers, IUCRCs are relatively small, moderately multidisciplinary, and focused on research that borders on pre-competitive/translational research compared to these larger and better-funded CRCs. Since most center research projects are theses or dissertations, student training and development are a major component of IUCRCs. While the average IUCRC supports 20 graduate students, collectively they support over 1600 students and over 500 receive graduate degrees each year. Like most areas of science about 50% of IUCRC students are not US citizens. Consistent with our focus on social capital outcomes all four of the IUCRC program's goals seem particularly relevant to a longer term capacity building focus (https://www.ncsu.edu/iucrc/NatReports.htm):

- Contributing to the nation's research enterprise by developing long-term partnerships among industry, academe, and government;

- Leveraging NSF funds with industry to support graduate students performing industrially relevant pre-competitive research;
- Expanding the innovation capacity of our nation's competitive workforce through partnerships between industries and universities; and
- Encouraging the nation's research enterprise to remain competitive through active engagement with academic and industrial leaders throughout the world.

4.3 Research design

A quasi-experimental design which involved matched samples of IUCRC-trained and traditionally-trained students was used to test the research hypotheses and questions.[6] This distinction represents the main independent variable—the type of graduate training.

Participants in the IUCRC conditions were identified and selected in the following manner: (1) Directors of IUCRCs were contacted and asked to participate in the study by providing contact information for the IUCRC students[7]; (2) An email invitation to participate in the study which included an endorsement from the center director was sent to students; (3) A total of two reminders were sent to the IUCRC students before data collection was completed; (4) A screening question was included in the questionnaire asking the students to confirm their involvement in an IUCRC and the name of the IUCRC they were involved with.[8]

In order to create a defensible comparison group of traditionally trained students (e.g. students who did not have a CRC-type experience), we attempted to create a matched sample comparison group. This group was created by first targeting the universities that were represented in the IUCRC sample and then obtaining email addresses for students who were matched on the following characteristics: graduate student status and degree majors (top five from IUCRC sample). In order to identify traditionally trained students the web-based questionnaire included the following screening question: "Which answer best described the research project you are engaged into satisfy your degree requirement?" Students who provided the following answers were excluded from the sample as they indicated experience similar to center experience: My Master's/PhD research project is one of a number of projects being performed under a multi-investigator research center or institute on my campus and is supervised by my main advisor and a thesis/dissertation committee ($N = 14$); Other ($N = 7$).[9] Table 4 in Appendix 1 includes descriptive statistics

[6] Following the recommendation of a priori power analyses of MANOVA with special effect and interactions, the objective was established to meet the minimum requirement of total 190 participants to achieve 90% power for a small size effect employing the traditional .05 significance criterion.

[7] Based on a 2012–2013 IUCRC Structural report's data, the total population of the site directors ($N = 191$) was contacted with the request to provide their university site's current students. Almost half of site directors (49%, $N = 94$) responded and provided their students' contact information. In addition, directors were asked to provide emails for students of different degree levels, but the study focused on Ph.D. students only.

[8] All procedures were approved by the North Carolina State University's IRB.

[9] It was important to compare the IUCRC students to students trained traditionally in order for the findings to be meaningful and generalizable to the pros and cons of different training modalities that exist today. While we acknowledge that our sampling criteria did not eliminate students who might, for instance, have had industry experience in other than CRC form, we think we reached our main objective by excluding students who had collaborative experiences similar to CRC. There is a good chance that a subset of traditional students had one-on-one experience with industry, but our objective was to eliminate students who had consortium-type of experience where they work as part of a team of scientists as supposed to being part of a more limited in collaboration contractual relationship that are more typical in the US academia.

for all available response options for the original sample and the final sample of traditionally-trained doctoral students. Table 5 in Appendix 2 includes the final response rate for each group with 32% of IUCRC and 15% of Traditional groups' doctoral students providing their complete responses to the questionnaire. The final sample included 260 doctoral students, $N_{IUCRC} = 173$ and $N_{Traditional} = 87$. As will be described below, comparison on a variety of demographic variables revealed only one significant difference between the two conditions.

4.4 Measures

As was pointed out in our literature review, very little effort has been invested in the development of measure that taps into different aspects of STHC framework. As a consequence, the authors had to develop a number of the measures used in the study.

4.4.1 Social capital

Social capital measures attempted to tap into two dimensions: the better understood concept of students' professional networks (size and strength of those networks) and the less common psychosocial component of students' norms and values about collaboration with other professionals. For the professional social network, students were asked to "think of all scientists and engineers they know or they have interacted with in the past." The detailed categories included engineers and scientists across all sectors (e.g. academia, industry, non-profit), and postdocs and other students who are pursuing career in relevant disciplines.

The size of students' networks was measured by simply asking students to estimate the number of professionals they knew from 13 types of professionals. The thirteen types of professionals were combined into three categories based on a combination of logical grouping and factor loadings of the types: US academic network (six types were combined); international academic network (two types combined); and industry network (five types combined).[10]

The strength of students' network connections was measured using Likert-type scale items that measured the availability of "technical advice or input" and "introduction to another researchers" from five categories of professionals. The four categories were collapsed into three: US academics ("department academics" and "academics from other universities and disciplines in the US" were combined) and "international academics" and "industry."[11] The two measures of strength for each of three categories had significantly high correlations ranging from .550 to .645. Thus, the two measures were combined into a single measure of the strength of a professional network by summing their total scores.

[10] US academic professionals included: faculty from students' departments (1), graduate students and postdocs from department (2), faculty from other disciplines (3) and graduate students/postdocs (4) from the same university, and faculty (5) and graduate student/post-docs (6) from other universities in the US. International academic professionals included two categories: (1) faculty and (2) graduate students/postdocs outside of the US. Industry professionals combined five categories: representatives of (1) large companies, of small companies (2), of the US Federal or local government (3), nonprofit organizations (4), and associations/foundations (5). All categories were checked for extreme outliers that were recoded into the closest values on the distribution. Note, the industry professional network consisted primarily of representatives of industry (71%) while other types of representatives had smaller proportion: non-profit (9%), governmental organizations (10%) and entrepreneurs (10%).

[11] The network dimension of social capital includes the professional connections *excluding* students' academic advisor(s).

Table 1 Factor loadings of the norms and values items

Item	Loading
1. I believe that science benefits from involvement of different sectors such as private businesses, government and academia	.748
2. Sometimes, it may be challenging to work with people who come from different cultures, but the end results of such work are worth it	.564
3. I view collaborations between industry and academia as positive despite differences in the ways they operate and things they value	.661
4. I like working with researchers from different disciplines as I can use their knowledge in my area of work	.732
5. I believe that any contemporary scientist must have strong communication skills in order to be able to solve today's problems	.605
6. Despite extra time and resources spent on communication, I still think that working in teams is important for building innovation capacity	.590
7. Despite the challenges associated with bringing professionals from different disciplines to work together, I still think that such collaborations are important for science	.721
8. I believe that a problem-solving approach can contribute to science as much as development of theory	.743

Extraction method: Principal component analysis

1 component extracted

Although many social capital scholars highlight the importance of the psychosocial aspects of social capital such as trust and common norms and values (Bourdieu 2011; Lin 1999), few scholars have attempted to address these constructs empirically and none have for scientists. As a consequence, we rationally developed a set of items that attempt to tap into the norms and values about collaborative process. Therefore, this dimension of social capital attempted to measure the connecting mechanism or glue upon which networks can be built, maintained and developed. It also can be seen as consistent with the third dimension of social capital proposed by Lin (1999) that measures the likelihood of students to "mobilize" the resources embedded in their networks. The scale was built around a total of eight Likert-type five-response items ("strongly agree" to "strongly disagree.") Table 1 lists the items' loadings. Principal component analysis demonstrated one-factor solution and that the scale is reliable (Alpha = .820) and that the factor explains 46% of total variance. These results provide strong evidence for the structural validity of this proposed measure.

4.4.2 Satisfaction and career preparedness

Satisfaction with the overall graduate training experience was a simple single Likert-type item with five response options ranging from "dissatisfied" to "satisfied." The final measure was collapsed into an ordinal variable with three categories (neutral (N = 31) + mostly dissatisfied (N = 6) + dissatisfied (N = 3), mostly satisfied (N = 127) and satisfied (N = 93) in order to normalize the distribution.

The final outcome measure examined student's perceived career preparedness. Similar to social capital, studies on career preparedness of students' population demonstrate that assessment depends on the context, particularly, the students' discipline and the industry that hires them. There is also a notable distinction between the professional and academic programs. The measurement of career preparedness for graduates with professional degrees tend to be developed and tested psychometrically, especially, for medical professionals (Eley 2010; Goldacre et al. 2010; Kassim et al. 2016; Morrow et al. 2012). For example, there is a valid and reliable scale that measures self-report career preparedness of medical students—the Preparedness for Hospital Practice Questionnaire (Kassim et al. 2016). These types of measures rely not only on self-perception, but also on specific skills needed for a job (Kassim et al. 2016). On the other hand, the measurement of career preparedness in the context of academic or management degrees is more exploratory in nature (Daymon and Durkin 2013). Given the difficulty to predict the exact demands of such work, it is not surprising that no set measure of career preparedness is available in the context of science and engineering graduates. Thus, we created the measure of self-perceived career preparedness that focused on assessing students' professional skills and capabilities and asked them to rate themselves in comparison to their peers who were not involved with IUCRCs.[12] Students provided their response ranging from "fully disagree" to "fully agree" to four questions. For instance a sample item asked: "I think I have more necessary skills to make a valuable contribution to an organization that is going to hire me" Principal component analyses were conducted to test the items on their psychometric properties. The items loaded on a single factor that explained 61% of the variance. Reliability as measured by coefficient alpha .761.

4.4.3 Intention to remain in the US after graduation

Little is known about international students studying in the US besides just descriptive information on their demographics, enrollment and funding sources provided in annual Open Doors report by Institute of International Education (IIE 2016). Our study digs deeper into understanding international students by trying to capture how their graduate experience influences their intentions to stay in the US or go back to their home country upon their graduation. Specifically, students were asked "what are your personal plans after graduation?" and were given the following response options: a) go back to my home country; b) work for some time in the US and return to home country eventually; c) stay in the US permanently; and d) other. We expect that most graduate international students with or without undergraduate experience in the US are in a stage where they have considered this question while planning for their future. Moreover, options a and c can only be possible if students have a good understanding the employment landscape and what it takes to get a legal employment in the US for those who want to stay. Thus, this question is a good proxy for future choices of high skilled US-educated foreign born nationals.

4.5 Analysis

With one exception, there were no significant differences between the IUCRC and the traditional groups on a variety of demographic measures (self-report GPA, number of months enrolled in graduate school, age, gender and citizenship status). The two groups did differ on the distribution of disciplines with the traditional training modality having more students from computer science and engineering (45%) and material science and engineering (24%) than the corresponding IUCRC condition (10 and 13%) while numbering

[12] Traditional students had the same question, but it was worded differently to reflect their non-involvement with IUCRCs: "In comparison with other students in your department, … ."

fewer students from mechanical (2%) and electrical engineering (20%) than the corresponding IUCRC (25 and 27%).

Importantly, the sample's demographic profile was not significantly different from the US national population of S&E graduate students in terms of citizenship status and gender (NSF Science and Engineering Indicators, 2016). Consistent with national trends reported in our literature review and highlighted in our proposed research questions, over 50% of the study sample in both conditions were international students.

Since only one demographic variable, citizenship, was significantly correlated with any of the outcomes and it was already included in our analyses, we decided to not use these variables as covariates. Although the two training modalities differed by discipline, analyses controlling for this factor did not alter our results and are not reported. Finally, although we considered using MANOVA to evaluate the effect of training on our various social capital measures (network size, network strength and norms and values) the modest correlations among these variables and the exploratory nature of our hypotheses argued against this.[13] Thus, we choose to use ANOVA rather than MANOVA to test this hypothesis. More specifically, a set of two-way ANOVAs with the type of graduate training and citizenship status as predictors was performed to test the hypotheses and answer the research questions.

5 Results

The first hypothesis examined how training modality affects three social capital components: professional network size (a); professional network strength (b) and norms and values about collaboration (c). It stated that students trained at the IUCRCs exhibit more professional social capital than students trained traditionally.

The first set of social capital outcome measures addressed the size of three types of professional networks. Analysis of variance demonstrated that there was no significant training, $F(1, 253) = .985$, $p = .322$, $\eta^2 = .004$ citizenship status, $F(1, 253) = 2.691$, $p = .102$, $\eta^2 = .011$, and interaction effect, $F(1, 253) = .357$, $p = .551$, $\eta^2 = .001$, on the size of the US academic network. Citizenship status, $F(1, 252) = 33.986$, $p < .001$, $\eta^2 = .119$, was the only significant predictor of the number of the international academics where international students, not surprisingly, scored significantly higher on the number of the international academics in their network.[14]

The size of the industry network, was significantly predicted by the type of training, $F(1, 252) = 6.957$, $p = .009$, $\eta^2 = .025$, and citizenship status, $F(1, 252) = 6.576$, $p = .011$, $\eta^2 = .027$. Both, international and US students, reported a larger industry

[13] Three measures of size of each type of group (US academics, international academics and industry) were a continuous measure of total number of professionals in each group. Three measures of strength of connection to each type of group were the sum of two Likert-type measures with five response choices. The measure of norms and values was a scale (sum of eight Likert-type items with five response choices).

[14] The assumption of equality of variance was violated because of the large difference in variance between US citizens ($M_{\text{I-UCRC}} = 3.01$, SD = 4.13; $M_{\text{trad.}} = 5.32$, SD = 9.88) and international students ($M_{\text{I-UCRC}} = 16.03$, SD = 21.80; $M_{\text{trad.}} = 19.78$, SD = 25.05) on the outcome. Since transformation of variables with non-normal distribution and large variance was not successful, the non-parametric one-way ANOVA was used to test whether immigration status predicts the number of the international academics. The three non-parametric ANOVAs tests were performed to see whether the number of international academics differs based on citizenship status. All three were significant thus, the tests rejected the null hypothesis, Mann–Whitney U Test $p < .001$, Kolmogorov–Smirnov $p < .001$, and Kruskal–Wallis $p < .001$.

network in the IUCRC condition ($M_{\mathrm{intl}} = 11.43$, $M_{\mathrm{US}} = 17.56$) than their corresponding citizenship group in the traditional condition ($M_{\mathrm{intl}} = 7.90$, $M_{\mathrm{US}} = 11.29$). The interaction of the type of training and citizenship status was not a significant predictor of the size of industry network, $F(1, 252) = .545$, $p = .461$, $\eta^2 = .002$.[15] Thus, H_{1a} was partially supported as the IUCRC students acquired a larger network of industry professionals than traditionally trained students, but there was no significant difference in size of the US and international academic networks. With reference to RQ_1 we found that that citizenship status affects the size of two types of networks: international academic network and industry network where international students report significantly higher number of international academic connections than the US students and significantly smaller number of industry connections than the US students *regardless* of the type of their training.

The strength of one's network was the second social capital outcome of interest. The strength of the US academic network also was not affected by the IUCRC training, $F(1, 256) = .979$, $p = .323$, $\eta^2 = .004$ citizenship status, $F(1, 256) = .001$, $p = .978$, $\eta^2 = .000$, and interaction $F(1, 256) = .329$, $p = 567$, $\eta^2 = .001$. The strength of the international academic network was again significantly predicted only by citizenship status, $F(1, 256) = 15.432$, $p = .000$, $\eta^2 = .057$. As expected, international students, regardless of their training, reported stronger international academics network.

There was a significant interaction effect of training and citizenship status on strength of industry network, $F(1, 256) = 6.053$, $p = .015$, $\eta^2 = .023$ (See Table 2; Fig. 1). The effect of graduate training modality depends on students' citizenship status in that only US students trained in IUCRC condition acquired stronger industry network ($M_{\mathrm{US\ traditional}} = 6.447$, $M_{\mathrm{US\ IUCRC}} = 7.803$). The strength of international students' industry network was not affected by the graduate training ($M_{\mathrm{intl\ traditional}} = 6.510$, $M_{\mathrm{intl\ IUCRC}} = 6.495$). The additional analysis of simple main effects of the two independent variables showed stronger industry network for the US IUCRC students ($p < .001$), but there were no increase in strength of industry network for the international IUCRC students ($p = .967$). Thus, H_{1b} was also partially supported since strength of industry network was predicted by the type of graduate training. Interestingly, this effect was not realized by international IUCRC students.

The last social capital component was the norms and values scale. IUCRC training significantly predicted higher norms and values score, $F(1, 256) = 12.354$, $p = .001$, $\eta^2 = .046$ while citizenship status, $F(1, 256) = .785$, $p = .350$, $\eta^2 = .006$, and interaction, $F(1, 256) = .485$, $p = .342$, $\eta^2 = .008$, did not.[16] Thus H_{1c} was fully supported. IUCRC-trained students acquired more positive norms and values than traditionally trained students. The summary of the results with the social capital outcomes is included in Table 6 in Appendix 3.

H_2 was supported as well. IUCRC students were more satisfied with their graduate training than traditionally trained students, $F(1, 256) = 17.217$, $p < .001$, $\eta^2 = .063$. Citizenship status, $F(1, 256) = 1.256$, $p < .263$, $\eta^2 = .005$, and interaction, $F(1,$

[15] The assumption of equal variance was violated. Three non-parametric tests of one-way ANOVA were performed for each of the significant independent variables. The tests rejected the null hypothesis for both variables, Mann–Whitney U Test $p < .001$, Kolmogorov–Smirnov $p < .001$, and Kruskal–Wallis $p < .001$ (immigration status) and Mann–Whitney U Test $p < .001$, Kolmogorov–Smirnov $p < .001$, and Kruskal–Wallis $p < .001$ (the type of training).

[16] The assumption of equality of the variance was violated, so one-way non-parametric ANOVA was performed to see if the center and non-center students differ on this outcome. The tests results rejected the null hypothesis, Mann–Whitney U Test $p < .001$, Kolmogorov–Smirnov $p < .001$, and Kruskal–Wallis $p < .001$.

Table 2 The two-way ANOVA results for strength of industry network

Source	Type III sum of squares	df	Mean square	F	Sig.	Partial eta squared
Training	25.578	1	25.578	5.785	.017	.022
Citizenship	22.081	1	22.081	4.994	.026	.019
Training × citizenship	26.764	1	26.764	6.053	.015	.023
Error	1131.927	256	4.422			
Total	13,507.000	260				
Corrected total	1224.812	259				

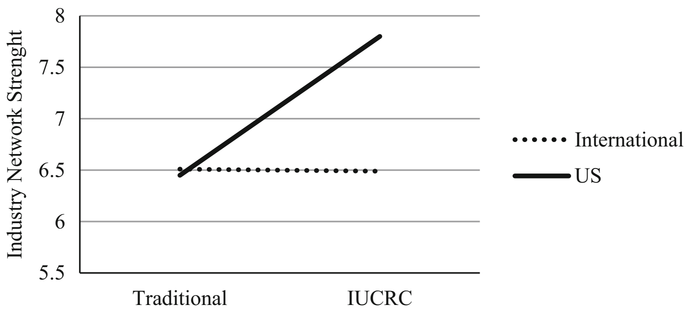

Fig. 1 Effect of the IUCRC training and citizenship on strength of industry network

256) = .749, $p < .388$, $\eta^2 = .003$, did not have effect on satisfaction which answers the research question 3.[17]

Finally, the results showed support for H_3 that stated that the IUCRC students will demonstrate higher level of perceived career preparedness than traditional students, $F(1, 256) = 35.507$, $p < .001$, $\eta^2 = .122$. The effect of citizenship status, $F(1, 256) = .091$, $p < .763$, $\eta^2 = .000$, and interaction of the graduate training and citizenship status, $F(1, 256) = 1.307$, $p < .254$, $\eta^2 = .005$, were not significant.

The answer to Q4 where international students had to indicate their plans after graduation did not reveal a significant effect but the direction of the effect were suggestive. On the one hand, the results of Chi square analyses showed that there was no significant differences between intentions of international students trained under different conditions, X^2 (2, 134) = 3.66, $p = .161$. On the other hand, the results showed a distinct pattern where the IUCRC international students were more likely to report intentions to stay in the US (33%) and then to go home (9%) than traditionally-trained students, 19 and 18% (Table 3). Interestingly, almost 90% of all international students indicated a preference to work in the US temporarily or permanently.

[17] Assumption of equality of variance was violated and the non-parametric one-way ANOVA was performed with three significant tests. The three non-parametric tests indicated that the null hypothesis can be rejected, Mann–Whitney U Test $p < .001$, Kolmogorov–Smirnov $p < .001$, and Kruskal–Wallis $p < .001$.

Table 3 Crosstabulation of international students' intentions by the type of training

Group	Go back to my home country	Work for some time in the US and return to my home country eventually	Stay in the US permanently	Total
Traditional N	7	27	8	42
Traditional %	16.7	64.3	19.0	100.0
IUCRC N	8	54	30	92
IUCRC %	8.7	58.7	32.6	100.0
Total N	15	81	38	134
Total %	11.2	60.4	28.4	100.0

6 Discussion and conclusion

In the current paper, we have attempted to address some challenges associated with "soft" capacity building metrics and to contribute to a more comprehensive understanding of the application of an STHC-based evaluation framework. In spite of Bozeman and his colleague's (2001) exhortations to expand our evaluation purview beyond microeconomic outcomes and include capacity building outcomes such as STHC, relatively few empirical studies of STI initiatives have pursued this line of research. Surprisingly, this has also been the case for CRCs which because of their highly collaborative structure and processes seem likely to produce STHC benefits. A variety of factors have contributed to this state-of-affairs, including under-developed STI-specific theory, methods and instruments. Given this background, we implemented a quasi-experimental study to examine the social capital and related outcomes of participating in a specific type of CRC—IUCRCs—on an important but neglected population—graduate students trained in these centers.

Our findings appear to provide partial support for some of our hypotheses and full support for others. We found that IUCRC training had an effect on some components the student's social networks but not on others. Specifically, in spite of a belief that IUCRC students would have more team-based training experiences, there were no differences between these students and traditionally-trained students on the size and strength of their US academic network. Similarly, in spite of a belief that organized centers such as IUCRCs would have expanded opportunities for international collaboration, there were no differences between these students and traditionally-trained students on the size and strength of their international academic networks. On the other hand, the expectations are met for industry network: consistent with the rich opportunity they are afforded to interact with firms, IUCRC students did report significantly larger and stronger industrial social networks.

Perhaps the most intriguing findings from our study relates to the role a student's citizenship plays on social capital development. First, we found that international students report larger and stronger international social networks regardless of training modality. While this finding should not be a great surprise, it may have important policy implications. A number of federal STI agencies support programs to expand international scientific ties.[18] In addition, the IUCRC solicitation indicates "when appropriate, the IUCRCs use

[18] Examples are NSF's Partnership for International Research and Education (https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505038) and NASA's Intern and Fellow Opportunities for International Students (https://intern.nasa.gov/non-us-opportunities/index.html).

international collaborations to advance the program's goals within the global context" (Solicitation 17-516 2017). The important but overlooked truth is that roughly *half* of the S&E doctoral students trained in the US are international and, as our findings show, bring with them a rich international network. While this finding is consistent with STHC theory which highlights the longevity of professional social networks, we have seen little commentary about or policy action related to capitalizing on the untapped resources embedded in international students' networks (Lin 1999). This capacity represents network resources that may not be realized at the current moment, but are inherently part of international students' professional portfolio (Bozeman et al. 2001; Lin 1999).

Second and more surprising was the finding that training modalities effect on the strength (but not the size) of a student's industry social network was moderated by a student's citizenship status. According to our findings, while international IUCRC students appear to exhibit a larger industry network, the network is not as strong as the US students receiving the same training. Based on our participation in IUCRC meetings there are a number of reasons why these students may not be realizing this benefit including: language problems undermining effective communication; failure of US mentors to integrate international students into some of the more meaningful center interactions; and questions and uncertainties related to student visa status and ability to obtain jobs. These reasons are consistent with the importance of social and cultural capital addressed in the literature on international students and how its acquisition is affected by challenges associated with these students' adaptation to the new culture (Ingram et al. 2013). Nonetheless, since our "strength" measure reflects access to both strong ties (advice from individuals they know) and weak ties (introductions to other professionals), social capital theory (Granovetter 1983; Lin 1999) suggests the larger industrial network international IUCRC students are acquiring may not be particularly effective helping them access and mobilize scientific resources. Given the large number of international students who would like to remain in the US for employment (N = 119 or 89% of all international students in the study's sample which is higher than the national rate (Finn 2010), this must be considered a capacity building failure. Despite of non-significant results of international students' intentions, the patterns, where IUCRC international students indicate higher percentage of staying in the US and lower percentage of going home than traditionally-trained students, are also very intriguing. Given the limited literature on factors that affect the retention of international students, the suggestion that training modality might have an influence may be worth additional research.

Finally, it is important to remember that at a more global level our results also demonstrate that IUCRC training has a significant positive effect on students' satisfaction with their graduate training and higher perceived career preparedness which supports existing knowledge about positive effects of the CRC training (Boardman and Gray 2010; Coberly and Gray 2010; Gray and Steenhuis 2003; Schneider 2007). How much of these effects are due to reported differences in social capital or other IUCRC processes is an interesting question but falls outside of the scope of the current paper.

6.1 Limitations

While we think our study has a number of methodological strengths including the rare use of a quasi-experimental study to assess social capital impacts, we also want to acknowledge some limitations. The first issue relates to generalizability of our findings (Shadish et al. 2002). As we have pointed out earlier, CRCs tend to be very heterogeneous in terms of goals, operations, funding levels and other factors. For instance, other US-based CRCs put much more emphasis on team-based collaboration and much less on industry interaction than IUCRCs. CRCs supported by the EU and Australia tend to differ on a number of dimensions. Thus, it is important to emphasize our findings may not be apply to all CRCs.

Second, our control group, the traditional training modality group, may not be a perfect representation of the group of students who experience most traditional type of academic training because we could not possibly investigate all aspects of their training. For instance, traditional students may have previously had a CRC experience. Nonetheless, we think our control group is a reasonable sample of students who are receiving the more traditional dyadic and committee-driven training many students receive.

Third, given the poor state-of-the-art with respect to measure availability, we did not have the luxury of using established STI-specific social capital, satisfaction and perceived career preparedness measures and had to develop our own. Even though our measures had relatively good psychometric properties, additional studies can help to validate them using new sample of doctoral students. In particular, there is a great need to go beyond our relatively straight forward network size and strength measures of social capital and use Social Network Analysis-based methods to provide a more precise and granular understanding of social capital impacts.

Finally, the small effect sizes of the ANOVA models[19] demonstrate that additional predictors of the students' outcomes would be valuable. For example, we are very aware that there is also great variability across IUCRCs in terms of how much emphasis they place on team-based collaboration, interaction with firms, experiential training focus and these factors as well as other student difference beyond international student status, if taken into account, may improve the effect sizes.

6.2 Implications

Much of the evaluative attention directed at CRCs tends to focus on the very important but relatively straight forward technology transfer and microeconomic impacts of these highly collaborative initiatives on member firms (See Boardman and Gray 2010 for representative collection of evaluative research). This focus appears to be consistent with what we and others perceive to be a bias in our STI evaluative methods. We believe our findings highlight both the feasibility and desirability of complementing this type of research with studies which target populations (students) and outcomes (social capital) that emphasize the longer term capacity building potential of these initiatives. As demonstrated in the method and results sections of this paper, the STHC evaluation framework can not only be applied to the existing STI programs and projects, but also can provide a different types of insights into these programs' impacts on both, specific stakeholders, like international or US students, and potentially missed opportunities to capitalize on the processes that are already in place.

According to the most recent report by the National Academies Press on A New Vision for Center-Based Engineering Research, "capacity-building through students' development and training … and direct engagement with industry" is and should be one of the main objectives of CRCs (The National Academies 2017, p. 40). And, our research adds to

[19] 13% of variance in size of the international academic network; 8% of variance in strength international academic network; 8% in variance in strength of the industry network variable; 6% of variance in the norms and values; 7% variance in satisfaction; 12% of variance in students' preparedness.

a growing body of literature that supports this multi-faceted value delivered by CRC training (Gray et al. 2013). Our findings suggest additional benefits for students trained in IUCRCs in the form of larger and stronger social networks. Consistent with the notion of capacity building outcomes these networks may provide value long after the student graduates. At the same time the IUCRC program does not appear to be a STHC panacea since the social capital benefits were not as broad or as universal as we had hypothesized. We suspect that CRCs which differ by size and operational procedures may produce different profiles of social capital benefits. If this is the case, it would behoove program designers and managers to investigate these differences and try to design a CRC which produces a broad spectrum of social capital benefits. Similarly, given the size and importance of international students to the US system of STI human capital, steps could and should be taken to capitalize on their existing international social networks while insuring that they are not short changed on the strength of the industrial social capital they receive.

In spite of non-significant results for international students' immigration intentions, our findings may serve to highlight broader immigration-related issues. The type of graduate training, involvement of students in CRCs and dosage of different experiences, may influence international students' intentions to build their future lives in the US or to go back to their home countries. For example, 58% of science and engineering highest degrees' recipients are employed by industry (National Science Board 2016). At the same time, the process for acquiring the work visa (H1B) to work at the for-profit organization is much harder and more competitive than for the same visa to work at university settings or non-profit. Given our results, IUCRC international students who have more exposure to industry have an upper hand in landing a job with the private sector because of the relationship they may establish with a company *before* they graduate. This timing is very important for acquiring H1B visa as it takes months and in some cases years to obtain it. In the current uncertain times when formerly praised globalization is perceived to be responsible for range of economic and social problems in the US, it is important to understand factors that influence these students' intentions. While there are pros and cons of high skilled immigration to the US, the US has been reliant on it for too long to survive without it. Understanding the shifts of the high skilled immigration trends is valuable not only for the US scientific and technical capacity but also for its economic and social stability.

Appendix 1: Screening question

See Table 4.

Table 4 Responses to screening question by traditionally-trained students[a]

Response option	Initial sample		Final sample	
	Frequency	Percent	Frequency	Percent
My Master's/PhD research project is an individual project that is being supervised by my main academic advisor(s) and thesis/dissertation committee	101	61.6	64	73.6
My degree does not require a thesis or dissertation	0	0	0	0
My Master's/PhD research project is part of a larger team-based project but is still supervised by my main advisor(s) and thesis/dissertation committee	36	22.0	23	26.4
My Master's/PhD research project is one of a number of projects being performed under a multi-investigator research center or institute on my campus and is supervised by my main advisor and a thesis/dissertation committee	14	8.5	0	0
Other (please, explain)	7	4.3	0	0
Total	164	100.0	87	100.0

[a] PhD students only

Appendix 2: Response rate

See Table 5.

Table 5 Response rate

Response categories	Frequency	Percent	Frequency	Percent
Sent to	1019	100	1399	100
Responded (with missing data)	612	60	398	28
PhD only (with missing data)	313	31	166	12
Approximate N of PhD respondents	550	100	588	100
Final response rate	173	32	87	15

Appendix 3: Results summary

See Table 6.

Table 6 Summary of the two-way ANOVAs

	Training	Citizenship	Interaction
Size US academic	–	–	–
Strength US academic	–	–	–
Size international academic	–	F = 33.986, $p < .001$	–
Strength international academic	–	F = 15.432, $p = .000$	–
Size industry	F = 6.957, $p = .009$	F = 6.576, $p = .011$	–
Strength industry	F = 5.785, $p = .017$	F = 4.994, $p = .026$	F = 6.053, $p = .015$
Norms and values	F = 12.354, $p = .001$	–	–
Satisfaction	F = 17.217, $p < .001$	–	–
Preparedness	F = 35.507, $p < .001$	–	–

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