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Longitudinal perspectives of faculty and students on benefits and barriers to transdisciplinary graduate education: program assessment and institutional recommendations

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ABSTRACT Addressing complex societal problems, such as childhood obesity, requires transdisciplinary (TD) approaches to reach effective solutions. However, TD doctoral training programs in academic settings are still relatively new, and little is known about the benefits and barriers of participation. This study sought to longitudinally assess benefits and barriers of a TD approach to doctoral education from the perspectives of students working towards a joint PhD/MPH degree and their faculty advisors. Results show that benefits across 5-years included greater collaboration and networking, enhanced guidance and support, broadened ways of thinking, and expanded opportunities. Barriers included time demands, complicated logistics, and tension between depth versus breadth of knowledge. Similarities and differences among students and faculty are discussed. Findings provide resources for both faculty and students considering involvement with TD doctoral education, as well as for institutions and academic programs seeking to promote TD training and team science.

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Introduction

Addressing complex societal problems demands coordinated effort from many sectors, stakeholders, and disciplines (World Health Organization, 2016). Increasingly, the concept of convergence between life sciences, engineering, social sciences, and other fields is viewed as a key to unlocking innovative solutions to complex global problems such as childhood obesity (National Research Council (NRC), 2014). Higher education plays a critical role in teaching and cultivating transdisciplinary (TD) team science, which we define in this paper as approaches that vertically integrate theories and bodies of knowledge across diverse disciplines and horizontally integrate approaches from stakeholders at multiple levels of the social ecology from individuals and families to communities to policy makers, in order to generate novel ways to address grand challenges (Bernstein, 2015; Hirsch et al., 2008; Jacob, 2015; Neuhauser et al., 2007; Neuhauser and Pohl, 2015; Stokols, 2006, 2013). However, the institutional and programmatic infrastructure and practical pedagogical strategies to support training in TD science are still emerging (Jacob, 2015; NRC, 2014; Neuhauser et al., 2007; Willetts and Mitchell, 2016).

TD research promotes integration across intrapersonal, interpersonal, organizational, community, and societal levels on social problems (Abrams, 2006; Stokols et al., 2013) such that traditional disciplinary boundaries become blurred (Townsend et al., 2015). Utilizing teams of researchers from a variety of fields is critical, as one discipline alone cannot provide all the answers. Thus, educational programs that teach TD approaches go beyond multi-disciplinary and interdisciplinary in order to foster syntheses across academic disciplines while seeking input from non-academic stakeholders (such as practitioners and policy makers) in order to solve real societal problems (Wall and Shankar, 2008). Such efforts are designed to yield new ways of analyzing and solving problems from multiple stakeholder perspectives and at various levels of inquiry (Bernstein, 2015; Harrison et al., 2011; Stokols et al., 2013).

Additional programs and pedagogies in higher education are needed to promote TD learning. Furthermore, these programs must be critically examined and evaluated, so that we can move toward using evidence-based TD education (Shandas and Brown, 2016). There is growing attention to evaluating TD training. For example, recently Willetts and Mitchell (2016) have proposed a framework for evaluating the dissertation examination process of TD doctoral research, including quality criteria. The potential benefits and barriers of TD training may be similar to those previously identified in *interdisciplinary* doctoral programs, which in some instances have been defined similarly to TD programs (Graybill et al., 2006; Bosque-Pérez et al., 2016). Graybill and colleagues (2006) found that doctoral students in an interdisciplinary program struggled with academic identity, what to prioritize, and academic productivity. Other studies have identified TD training challenges and TD approaches among faculty and scientists such as learning to speak the language of multiple disciplines, navigating between disciplines, managing criticism from those working in single disciplines, and concerns about TD approaches lacking focus (Nash, 2008; Neuhauser, 2007; Stokols et al., 2008a; Vanasupa et al., 2012). Potential benefits of TD approaches also warrant exploration. One study that evaluated teams of established TD scientists at large research centers, reported a benefit of increased scientific productivity compared to disciplinary approaches (Cooper et al., 2013; Hall et al., 2008, 2012). However, little is known about the benefits and barriers over time of participating in emerging TD doctoral education programs as perceived by both faculty and students.

The formation of this TD training program was a result of the increased urgency to address the complex global public health

crisis of childhood obesity (Harrison et al., 2011; Nishtar et al., 2016). In 2007, a campus collaboration began forming, and members developed a shared ecological model of childhood obesity, proposed a research project together, and obtained state funding to conduct a prospective panel study and sub-projects. Out of this collaboration, the vision for a TD doctoral training program emerged and a leader stepped forward. A team of thirteen faculty from nine disciplines were brought together to develop a TD training program to equip doctoral students with the cross-disciplinary tools to address childhood obesity prevention and public health. This group sought and secured funding for this innovative opportunity through the USDA in 2011. The purpose of this study was to explore the benefits and barriers to being involved in a TD doctoral training program from the perspectives of faculty and their students. This study also aimed to generate new insights to inform and guide institutions seeking to facilitate more TD education, faculty making decisions about investing time in TD endeavors, and students considering TD doctoral training.

Methods

This study is part of a larger comprehensive evaluation of a federally funded TD doctoral program. To answer the research questions of this exploratory longitudinal study, data from focus groups were utilized to identify benefits and barriers of a TD approach from the perspectives of faculty and their students during the first five years of the TD program (2011–2015).

TD program description. This federally funded TD training program, started in 2011, is a joint PhD and Masters of Public Health (MPH) degree program that integrates education, research, and practice. A total of 13 students have been enrolled in this program (four in 2011, four in 2012, and five in 2013). It includes MPH coursework, capstone project, and practicum (or prior MPH degree) and a full disciplinary doctoral degree. In addition, students take courses in TD approaches to childhood obesity prevention, and conduct TD research projects. The program provides opportunities for broad cross-disciplinary interactions between faculty and students with leading international researchers, community stakeholders, and practitioners through a visiting faculty program, lecture series, capstone project, practicum, and biennial symposium (<http://i-topp.fshn.illinois.edu/>). The practicum and capstone project give students critical exposure to transdisciplinary settings of practice where complex challenges are revealed (McDaniels and Skogsberg, 2017), and this applied experience then shapes their TD research questions and collaborations. Students are provided with annual travel funds to present at conferences, and opportunities to apply for seed grants to support their dissertation research. A program coordinator supports the daily operations, collects and analyzes program evaluation data, and arranges team-building and professional development opportunities. The structure of this TD program allows students to learn the terminology and basic research approaches of other disciplines, while developing depth in their primary discipline. Thus, they develop their professional identity in a context informed and broadened by exposure to cross-disciplinary models, theories, and methods that promote a TD mindset. Students are mentored by a primary and secondary advisor from two disciplines, in consultation with other faculty and visiting scholars. Students meet with their Advisory Committees (faculty from at least three disciplines) at least yearly to select courses, develop their TD research, and set annual research and professional development goals reflected in an annual individual development plan that is also reviewed and approved by the I-TOPP Annual Student Review Committee.

Participants. Participants included faculty advisors (all 13 at baseline and 8 of 13 at five years) and their doctoral students (13 at baseline and 11 at five years) who were part of the TD program; students were from five and faculty from nine disciplines (i.e., Food Science, Nutrition, Human Development and Family Studies, Kinesiology, Community Health, Agricultural and Consumer Economics, Animal Sciences, Social Work, and Medicine).

Faculty participated in one of three focus groups at two time points (fall 2011 and fall 2015). Each faculty focus group consisted of 2–5 participants and the same combination of faculty was maintained in each focus group at both time points. Eight faculty had less than four years of prior TD experience. At baseline, faculty had been employed 13.7 ± 7.8 years at 1.4 ± 0.6 academic institutions; eight were female (62%), three were assistant professors (23%), five were associate professors (38%), and five were full professors (38%). One faculty left and one joined the program; all 13 faculty were invited to participate with the same focus group at each time point. At five years, nine were female (69%), one was assistant professor (8%), three were associate professors (23%), and nine were full professors (69%). They self-identified as non-Hispanic African-American (1), non-Hispanic Asian (1), Hispanic White (1), and non-Hispanic White (10).

Students participated in one of three focus groups with their academic cohort upon joining the program (fall 2011, 2012, or 2013) and again in fall 2015. Each focus group consisted of 3 to 5 students, as they participated in the same cohort group for both time points. Since the second time point was five years into the training program, students in cohort 1 ($n = 3$) were in their fifth year of training, cohort 2 students ($n = 3$) were in their fourth year of training and cohort 3 students ($n = 5$) were in their third year of training. At baseline, students were 25.1 ± 3.3 years of age and 11 were female (85%). Students self-identified as Hispanic multi-racial (3), Hispanic White (1), non-Hispanic Asian (3), and non-Hispanic White (6). Students had completed 1.2 ± 1.8 years of graduate school at enrollment. At five years (fall 2015) two students had exited the program, so 11 students participated in the follow-up focus groups. The two students who left the program did so before the second year; one was more inclined to a mono-disciplinary approach and the other had not made satisfactory progress.

Focus groups. A focus group design was selected to identify the broadest possible understanding of perspectives and opinions at a group level rather than individual level, and it is a commonly used method in program evaluation to elicit the widest range of experiences (Hesse-Biber and Leavy, 2011). Furthermore, no standardized measures of benefits and barriers to TD education were available. Focus groups are used to measure a program's success, strengths, and weaknesses and to give a qualitative view of what is and is not working (Carey, 1994; Hesse-Biber and Leavy, 2011; Morgan, 1996; Morgan and Krueger, 1993). Focus groups yield data via a dynamic interactive process among individuals to assess "group effect" (Carey, 1994; Hesse-Biber and Leavy, 2011; Morgan, 1996; Morgan and Krueger, 1993). The group effect is greater than the sum total of individual interviews because participants can question and explain their answers to each other and this interaction indicates how similar or dissimilar each participant's experiences are (Morgan, 1996).

The focus group questions were developed by the TD assessment committee. The protocol was approved by the University's Institutional Review Board and informed consent was obtained prior to participation. The analysis for this study was based on responses to several open-ended questions from the larger protocol (e.g., *Compared to a traditional PhD program, what do you think are the benefits [barriers] to students and to faculty of participating in the program?*). Focus groups of five or fewer participants were scheduled separately for faculty and students. Three focus groups were conducted among faculty, and three among students at baseline (cohort 1 in fall 2011, cohort 2 in fall 2012, and cohort 3 in fall 2013) and after five years into the program; six focus groups at each time point. The same people were invited to participate in each focus group at each time point to ensure continuity within the groups. Focus groups were conducted by a trained, experienced external facilitator and were audio recorded and transcribed for analysis to enhance rigor and lower risk of error (Krueger and Casey, 2001).

Analysis plan. Transcripts were analyzed by the research team using a semantic approach to thematic analysis (Braun and Clarke, 2006) to identify benefit and barrier themes. Consistent with a realist epistemology, the semantic approach identifies explicit or surface meanings of the data (Braun and Clarke, 2006), summarizes them, and interprets their meaning, rather than examining the underlying constructs of the data. Data were analyzed using Dedoose (Version 7.0.23, Dedoose 2016).

We followed steps consistent with thematic analysis (Braun and Clarke, 2006). First, the research team read the focus group transcripts. The team then re-read the

transcripts together and used discussion and consensus to identify codes. After agreement was reached about the preliminary coding structure, two members of the team coded the remaining sections of the transcripts, using this coding structure while allowing new codes to emerge. When coding was completed, the primary analysts searched for themes within the codes. The individual codes were sorted into similar categories and themes were created to conceptually organize the coded data. The analysts kept memos to define and describe the themes in more detail to ensure coding consistency. Themes were reviewed, named, and transcripts were re-read to ensure codes were not missed. In the final stages, key concepts were extracted from quotes to describe themes, and overarching meta-themes were identified (Ryan and Bernard, 2003). All codes and themes were reviewed by the team to ensure agreement (Lincoln and Guba, 1985).

Below are two examples to illustrate the semantic approach to thematic analysis.

Theme: broadens ways of thinking/doing/answering

Quote from faculty at five years: "Well, I think that the lecture series, the invited speaker series has been really, really good. I think it has exposed both faculty and students to a wide variety of really high profile people. It's been really stimulating."

Quote from students at five years: "I think it's created a lot of opportunities for us to work in different ways. I know that I'm very stubborn, and probably would still do the kind of dissertation project that I wanted, but I know that I have a justification for wanting to bring things from outside of our field."

Theme: increases opportunities

Quote from faculty at five years: "I think the fact that there is certain funding allocated for the professional development of the students is very important. I think, also, the fact that as they work toward their degree, they have an option to participate in the Seed Grant Program. So, they're getting an opportunity to write these smaller grants, which will be important, especially if they're going into academia...and they're also getting some experience articulating their ideas in a way that's going to be important in the long term."

Quote from students at five years: "We have the opportunity to explore collaborating themes, using different styles, and apply them in our work. [I-TOPP] gives you that opportunity to be flexible and allocate your interests to the things that are priorities to you"

Themes discussed in this paper were mentioned in two or more of the faculty or two or more of the student focus groups, as aligned with a data reduction approach for qualitative data (Namey et al., 2008). This was important since the three student cohorts had varying training times of 3–5 years in the program. Finally, we conducted a member check (Lincoln and Guba, 1985); tables and figures were shared with all participants for feedback, and respondents agreed that codes and themes represented their perceptions.

Results

The study found numerous themes related to benefits and barriers to involvement in a TD training program among faculty advisors and doctoral students, as shown in Tables 1 and 2 and elaborated upon below in each section. First we report on themes of actual experiences in the program after five years (vs. baseline anticipated benefits and barriers). Second, we compare perceptions at baseline and at five-years in order to gain a longitudinal perspective on anticipated vs. actual benefits and barriers.

Faculty benefits and barriers

Benefits. At five years, five themes emerged regarding faculty opinions of benefits of participating in a TD training program: (a) broadens thinking, (b) builds networking and collaborations, (c) increases opportunities, (d) increases guidance and support, and (e) enriches faculty scholarship by way of TD students (Table 1). The first four themes were mentioned by all three faculty groups

Table 1 Benefit themes mentioned by two or more faculty or two or more student focus groups at baseline and after five years^a

Theme category	Key concepts	Faculty		Students	
		Baseline	5-years	Baseline	5-years
Broadens ways of thinking/ doing/ answering	Broadens thinking, different perspective, expanded view, more tools, multiple levels, new questions, resourceful, outside of the box	3	↔ 3	3	↓ 1
Builds networking & collaborations	Access, collaboration, conferences, connections, expanding, guest speakers, networking, socialization, team	3	↔ 3	3	↓ 2
Increases opportunities	Collaboration, exposure to experts, flexibility, funding, impact, policy change, support	1	↑ 3	2	↑ 3
Increases guidance/ attention/ support	Bond, cohesive team, confidence, faculty support, friendly competition, funding, network, shared passion, social support, structure	2	↑ 3	0	↑ 3
Enriches faculty scholarship via TD students	Enriching faculty work, learning process, more tools, new questions, new research, students are glue	2	↔ 2		
Connects past to current/ future	Build, expanding, learn from mistakes, Other TD programs	2	↓ 0		
Provides dual degree	Co-mentor, interconnectedness, knowledge base, tools, variety of classes	2	↓ 0		
Increases potential for real-world impact	Future careers, government, obesity epidemic, policy	2	↓ 0		
Improves science	Broad understanding, collaboration, depth of knowledge, many ways to answer questions, resourceful	2	↓ 0		
Exposes students to multiple perspectives	Breadth of knowledge, depth of knowledge, different, knowledge pathway, varied perspectives	3	↓ 0		
Places faculty/ students on cutting edge of research	Current, opportunity, frontlines, state of the art	2	↓ 0	1	↓ 0
Connects research to practice	Communication, community, impact, interconnectedness research, intervention, prevention, policy, theory	3	↓ 0	3	↓ 0
Benefits career	Build CV, flexibility, frontline, networking, opportunities, resources			3	↓ 1
Connects academics with personal interest	Community, helping others, intervention, making a difference, personal experience			3	↓ 0
Encourages research focus in TD	Broader impact, community, flexibility, intervention, prevention, research, shared goals, teamwork			3	↓ 0

TD transdisciplinary
 Note: Arrows indicate change or no change in number of focus groups in which a given theme was discussed from baseline to five-years. Key concepts were extracted from quotes to describe themes. Themes are organized by those mentioned most frequently to infrequently by faculty at the five-year time point. Themes in this table were mentioned by either two or more faculty focus groups or two or more student groups. Three additional benefit themes were identified but did not have sufficient support to include in this table, as follows: Increases funding (mentioned by one student and one faculty focus group), Attracts higher caliber students (mentioned by one faculty focus group), and Cultivates safe, accepting environment (mentioned by one faculty focus group)

Table 2 Barrier themes mentioned by two or more faculty or two or more student focus groups at baseline and after five years^a

Theme category	Key concepts	Faculty		Students	
		Baseline	5-years	Baseline	5-years
Creates concerns for faculty advancement	Advancement, documenting scholarly productivity, evaluation, incentives, inconsistent expectations, overwhelming for junior faculty, time, value	2	↔ 2		
Complicates balancing depth/breadth	Balance, career opportunity, depth, breadth, focus, identity, impact, imposture syndrome, relevance	2	↔ 2	2	↓ 1
Creates student time concerns/ places too much on plate	Comparison, expectations, logistics, longitudinal research limitations, overwhelming, pressure, relevance of coursework, sleep, timeline	0	↑ 2	2	↑ 3
Complicates logistics	Administration barriers, asking questions, communication, defining research focus, department differences, inventing the wheel, publishing, requirements, scheduling, sustainability, time, value	3	↓ 2	3	↓ 1
Causes internal conflicts for faculty	External criticism, guilt, insecurities, overwhelmed, personal barriers	2	↓ 1		
Magnifies faculty time/pressure concerns	Colleague pressure, commitment, difficult, overwhelmed, time management, time sink, two fulltime jobs	2	↓ 1		
Creates mentoring concerns	Effective guidance, rogue qualities, student independence	3	↓ 1		
Requires immediate sacrifice for uncertain future gain	Hard to balance, large commitment, time, unclear benefits	3	↓ 0		
Spawns disciplinary disagreements /boundary disputes	Artificial boundaries, departmental differences, different points of view, disadvantage, disagreements, ego, grounding in one discipline, jargon, silos	2	↓ 0	3	↓ 0
Generates negative perception of TD	Challenge to think outside of the box, complex, criticism, design challenges, expertise, isolation, logistics of publishing, method challenges, no precedent, requires true integration, silos	1	↓ 0	3	↓ 0
Makes providing clear and collective expectations difficult	Biases, culture, departmental differences, differences in advisors, high expectations, inventing the wheel, miscommunication, personal expectations			2	↑ 3
Limits research to practice	Individual biases, intervention limitations, lack of control, public			2	↓ 0
Magnifies challenges of working with multiple departments	Balance, communication challenges, departmental inconsistencies, isolated from home department, jargon, knowledge of other departments, red tape, time			3	↓ 1

TD transdisciplinary
 Note: Arrows indicate change or no change in number of focus groups in which a given theme was discussed from baseline to five-years. Key concepts were extracted from quotes to describe themes. Themes are organized by those mentioned most frequently to infrequently by faculty at the five-year time point. Themes in this table were mentioned by either two or more faculty focus groups or two or more student groups. Six additional barrier themes were identified but did not have sufficient support to include in this table, as follows: Gives students too many advantages (mentioned by one student focus group and one faculty focus group), Results in a lack of identity (mentioned by one student group), Generates university level concerns, Grants too much student independence, Raises student fit/motivation concerns, and Magnifies teaching/ course concerns (mentioned by one faculty focus group)

and the last theme by two groups. Broadened thinking during the past five years stemmed from the TD lecture series, stimulating intellectual exchange across fields, and the need for students to stretch themselves cognitively to succeed in required TD courses. Examples of networking included students having multi-disciplinary advisors and opportunities for peer collaboration among students and among faculty TD mentors. All faculty groups noted increased opportunities for TD students such as access to obtain seed grant funding to propose and conduct research projects with TD peers, and opportunities to collaborate

with researchers in other disciplines. One faculty member said, “It’s something about the structure of being in a TD program that emboldens them and I think makes professors more receptive than say just a random social work student wanting to connect with a rat [rodent] researcher...because they’re in this program, it validates that desire to reach out across disciplines.” Faculty noted the increased guidance, attention, and support for TD students through team-building events, multiple faculty mentors, and a formal annual review. “The students really put effort into tracking their products... We put effort into helping them establish goals

and targets. It's just different... it's very high quality annual review, and with a multi-disciplinary faculty."

Finally, two faculty groups talked about how TD students enrich faculty scholarship. One faculty member described students as "the glue that helps it [TD collaborations] work." Faculty noted that TD students altered their own research trajectory: "...I think in the course of this project, I actually started to go into another direction in terms of research. I think one of the reasons that I was able to was because... it was easy for me to listen to the other people, and to figure out, "How do I look at this new area? How can I integrate that with what I am currently doing?"

Barriers. As shown in Table 2, three barriers persisted from baseline and one new barrier was identified at five years. Persistent themes included concerns about career advancement, balancing depth and breadth of research, and logistics. The new barrier noted was that students may have "too much on their plates" regarding time spent on additional coursework and how far they could push students to excel in multiple degree programs and domains. At both time points faculty reported more challenges for junior faculty than senior faculty regarding career advancement, tenure, unclear standards to evaluate TD work, and time investment given tenure expectations. Faculty noted that the university supports interdisciplinary work but that independent research capability was still the single most important quality valued by departments. They also discussed that for senior faculty, diversifying interests is viewed as a desirable goal at the university and department levels, but the same is not true for pre-tenured faculty.

Student benefits and barriers

Benefits. At five years, three prominent themes emerged regarding the benefits to students of participating in a TD program: (a) broader networking and collaborations, (b) greater learning opportunities, and (c) increased guidance, attention, and support from faculty and other students (Table 1). Two cohorts discussed the opportunity to network and collaborate with faculty and students in other departments and institutions. Greater learning opportunities mentioned included: exposure to experts, getting to take classes not available to traditional students, and funding to attend conferences. Finally, all three cohorts discussed increased guidance, attention, and support as a benefit from the TD program and having multiple advisors.

Barriers. At five years, two themes emerged regarding barriers of participating in a TD program for students: (a) time concerns and (b) unclear expectations (Table 2). Students had concerns about having too much to do and never enough time, and felt they were behind or under greater pressure compared to traditional PhD students mentored by the same advisors. Students voiced frustration about advisors' implicit expectations that they be at the same place in their research as traditional PhD students, despite the additional classes required for the MPH and TD training; though they noted that expectations varied by discipline and advisor. Some advisors expected their students to focus on the MPH the first two years, while others expected them to advance their doctoral research and earn an MPH simultaneously.

Longitudinal findings. Overall, more benefits and barriers were reported by faculty at baseline than at five years. Seven of the 12 benefit themes (Table 1) and five of the 10 barrier themes (Table 2) did not persist as themes at five years. Students also reported more benefits and barriers at baseline than at five years. Five of the eight benefit themes (Table 1) and six of the eight

student barrier themes (Table 2) did not persist as themes at five years.

Meta-themes. Finally, we examined the data and themes for potential meta-themes to illustrate the core findings in a more parsimonious way. This process condensed the 28 themes that were mentioned in two or more of the faculty/student focus groups at baseline and five years into six overarching themes (see Fig. 1). For benefits, three meta-themes emerged: (a) improves scholarship, (b) increases individual benefits, and (c) expands research impact. For barriers, three meta-themes emerged: (a) increases workload, (b) heightens potential for conflict, and (c) generates unique concerns about faculty promotion.

Discussion

This exploratory study sought to uncover the benefits and barriers of participating in a TD training program over time. Discussion of findings on benefits (Table 1) and barriers (Table 2) are organized by themes and are discussed below in comparison to baseline perceptions and current literature. We highlight overall program level recommendations based on meta-themes that emerged from each group of informants (Fig. 1). Finally, themes that persisted or emerged at five years are displayed in Fig. 2 in order to visualize convergent and divergent themes among faculty and students.

Faculty benefits and barriers

Broad range of benefits: potential retention incentives. Prior research has demonstrated gains in researcher productivity from working in TD teams (Hall et al., 2012), but this study identified a much wider range of benefits to individual faculty and potentially to the university over time (Table 1). For example, in academia, retaining talented faculty is a growing challenge. A 2013 survey of tenure track faculty ($n = 784$) at a major U.S. public research university found that more than a quarter reported intentions to leave the university within the next two years (O'Meara et al., 2013). Although greater salary was the main reason, faculty also reported the desire for greater collegiality in their unit (11%) and better work-life balance (12%) as reasons for leaving. Thus, the benefits reported in this study may help with faculty retention. In addition to increased productivity (Hall et al., 2012), TD collaborations enhance the potential for innovative scholarship, more collaborations, TD lectures, and greater faculty satisfaction, all of which may contribute to retention. These factors should be of interest to administration and may serve as motivation to initiate and incentivize TD collaborations university-wide.

Perceptions are not always actualized. A surprising finding was that a fewer number of benefits and barriers were identified by faculty at five years than at baseline; however it is unclear if this suggests that anticipated benefits and barriers did not materialize, or simply were not discussed at five years. For instance, students earn two degrees in five years, a clear benefit identified at baseline but not discussed at five years. Another example of a benefit that was anticipated but not reported at five years was the program's capacity to train students to conduct high impact, policy-relevant research. At five years, faculty indicated a more realistic goal was for students to build TD research skills as a foundation for an impactful TD career. Finally, faculty concerns about mentoring that were anticipated at baseline were reduced at five years. Concerns for faculty advancement still persisted at five years, which is similar to what Armstrong and Jackson-Smith (2013) found when they interviewed scientists working in interdisciplinary teams. What does this tell us? First, it may be that anticipated barriers can be successfully resolved over time; and

Benefits		Barriers							
Meta-themes	Themes	Meta-themes	Themes						
Improves scholarship	Broadens ways of thinking/doing/answering Enriches faculty scholarship via TD students Places faculty/students on cutting edge of research Exposes students to multiple perspectives Provides dual degree Improves science Connects past to current/future Encourages research focus in TD	Increases workload	Creates student time concerns/places too much on plate Magnifies faculty time/pressure concerns Requires immediate sacrifice for uncertain future gain Complicates balancing depth/breadth						
				Increases individual benefits	Heightens potential for conflict	Magnifies challenges working with multiple departments Makes providing clear & collective expectations difficult Spawns disciplinary disagreements/boundary disputes Generates negative perception of TD Complicates logistics			
							Expands research impact	Generates unique concerns for faculty promotion	Creates concerns for faculty advancement Causes internal conflicts for faculty Creates mentoring concerns Limits research to practice

Fig. 1 Meta-themes derived from themes related to benefit and barriers to transdisciplinary (TD) graduate training. Six overarching themes emerged from the original 28 themes that were mentioned in two or more of the faculty/ student focus groups at baseline and at five years

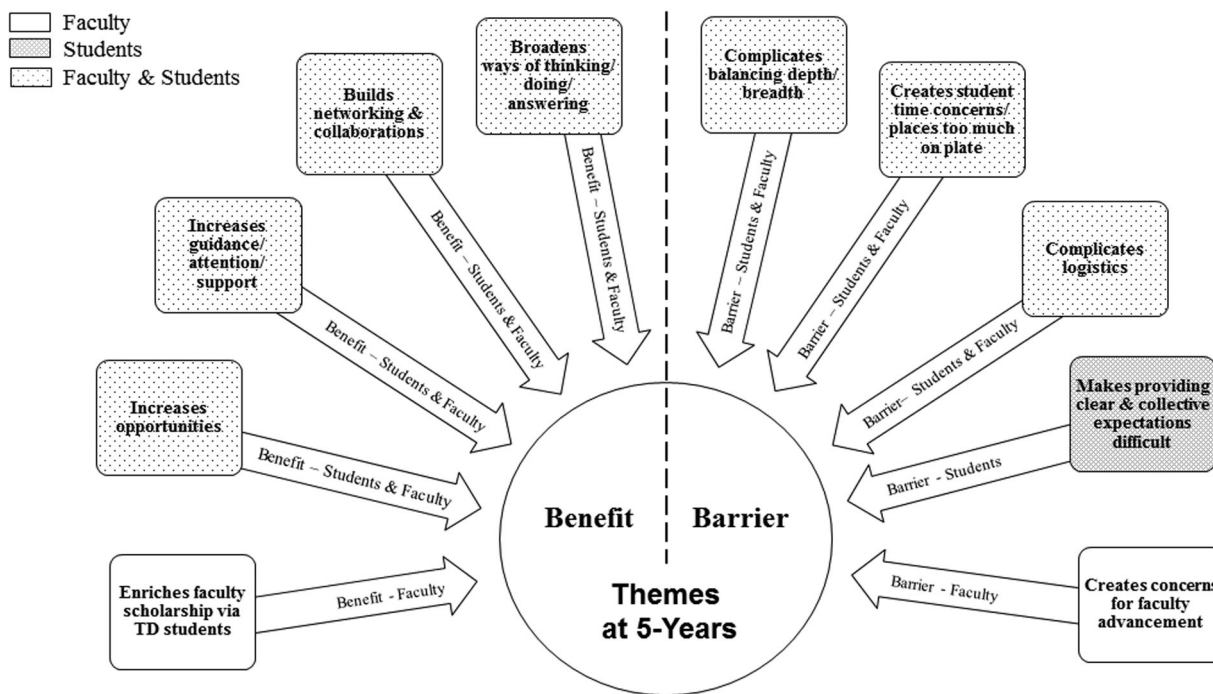


Fig. 2 Themes related to benefits and barriers to transdisciplinary (TD) graduate training at five years. Benefits and barriers discussed by only faculty at five years are shown on white background; benefits and barriers discussed by only students at five years are shown on crosshatched background; and benefits and barriers discussed by both faculty and student groups at five years are shown on dotted background

secondly, enumerating anticipated concerns at the start of a TD program may alert the team to address them pro-actively. Thus, we encourage TD planners and stakeholders to openly discuss but not be thwarted by anticipated problems.

Student benefits and barriers

TD and traditional students report similar experiences. Many of the well-documented challenges experienced by traditional

students overlap with those identified in this study among TD students. For example, traditional students have concerns about being inadequately informed about the doctoral training process, unclear expectations of advisors, and time to degree completion (Barnes and Randall, 2012; Liechty et al., 2009). In the current study, TD students also talked about their frustrations with unclear expectations from their multiple advisors and departments. Participating in TD training was a new experience for most involved, and expectations of each disciplinary doctoral

program differed, so the challenge of providing clear and collective expectations to students was not surprising. Other sources of stress noted in the literature among traditional students included lack of personal time and meeting program deadlines and requirements (Kurtz-Costed et al., 2006; Graybill et al., 2006). Similarly, all three TD cohorts also discussed concerns about having enough time to complete course work, making progress on their research, and having a personal life. Again, given the increased demands of a TD and dual degree program, time management is an expected challenge. However, despite students' stress about time pressure, all students in this study have graduated on time or are on track to graduate with two degrees in less than six years. We speculate that the additional program support and accountability of a focused TD program enables TD students to achieve timely degree completion.

Weaknesses of traditional programs may be strengths of TD programs. Traditional doctoral students have reported dissatisfaction with quality of mentoring and support from faculty and disappointment in the direction provided by their mentors (Nyquist and Woodford, 2000). In contrast, TD students in all three cohorts described ample attention and support from their faculty mentors and were aware that their non-TD peers may not always enjoy this benefit. Even if TD students received equivalent attention from one advisor as a traditional student, the fact that TD students have two or more advisors means they likely have more contact with faculty. Therefore, students in TD programs structured as described here are likely to experience increased attention and support (a benefit also reported among students in a doctoral interdisciplinary program, Bosque-Pérez et al., 2016). A second example is that traditional students reported frustration at the narrowness of required courses and lack of access to courses in other disciplines (Golde and Dore, 2001). One study even concluded that, "students enrolled in research intensive universities may not be getting the opportunities to publish, attend professional conferences, develop professional networks or gain teaching experience" (Barnes and Randall, 2012, p 69). In contrast, TD students in all three cohorts described having access to a wide variety of courses, the opportunity to present at professional conferences in multiple fields, and greater exposure to experts, all of which provided them ample opportunities to network and collaborate with researchers in other institutions and disciplines. These benefits are consistent with a TD mission and therefore not surprising; however programmatic support, cooperation among relevant departments, availability of funding, and leadership of the TD program will likely affect the degree to which these benefits can be realized by students in other TD programs.

Comparing faculty and student experiences

Faculty and students as co-learners. A prior study reported on benefits and barriers from the perspective of TD trainees (e.g., junior faculty, post-doctoral, and doctoral students) (Vogel et al., 2012). An important contribution of the current study is to prospectively evaluate a program from multiple vantage points. This allows for comparison between stakeholders in order to understand where experiences overlap or differ. The majority of benefit and barrier themes were discussed by both faculty and students at five years (see Fig. 2). Both groups talked about four benefits of being part of a TD team: broadened thinking, building new collaborations, and greater student support and opportunities. In addition, faculty talked about an additional benefit—that their own scholarship had been enriched from mentoring a TD student. Several of the barriers were also noted by both faculty and students, including balancing depth and breadth, time management and workload, and challenging logistics.

To our knowledge, this is the first study that has looked longitudinally at both faculty and student experiences together. The convergence in reported experiences suggests the program is generating similar benefits and barriers recognized by both faculty and students. Similarity of benefits may reflect the increased mentoring built into this program, which may have catalyzed a shared sense of broadened thinking and scholarly enrichment. Findings suggest that this mutual engagement with TD fostered a sense of collaborative discovery by faculty and students, thus enhancing students' experience of support. This type of co-learning is of interest because perceived faculty support is related to student program satisfaction, as well as student life satisfaction (Tompkins et al., 2016). While the TD students perceived a high level of support from faculty, students in traditional programs perceived lower levels of socioemotional support from faculty than from family, friends, and student-peers (Tompkins et al., 2016). Graduate school is a notoriously stressful endeavor and high stress can interfere with academic performance and degree completion (Lovitts, 2001). Therefore, despite TD students reporting a heavy workload, having greater shared experiences with faculty and opportunities for co-learning may mitigate student stressors. This is another potential important benefit of TD education of interest to those initiating or building TD programs at their institutions.

Meta-themes. The meta-themes identified six overarching themes: three benefits and three barriers (see Fig. 1) across students and faculty at both time points. The benefit meta-themes (improves scholarship, increases individual benefits, and expands research impact) highlight what participants of a successful TD program would hope to gain by their involvement and are consistent with the mission of TD education. The barrier meta-themes (increases workload, heightens potential for conflict, and generates concerns about faculty promotion) identify challenges for those involved with TD education. However, they also offer a platform for growth and improvement.

For instance, greater workload does not have to be viewed through a purely negative lens; under the right conditions, greater workload can inspire greater efficiency and productivity. Conflict also holds positive potential; when engaged constructively, conflict spurs growth (De Dreu, 2006). For example, the departmental and disciplinary boundary disputes noted at baseline were not mentioned by any focus group at five years; further, students and faculty alike noted the value of collaboration, networks, and support across and between disciplines and programs at five years. Regarding faculty promotion concerns, these may lessen as we approach a paradigm shift in the structure of academia and doctoral training, as TD science and collaboration become the new norm (Bennett et al., 2010; Chastin et al., 2016; Hirsch et al., 2008; Rimer and Abrams, 2012; Stokols et al., 2008b). Existing TD training programs must continue to gather and evaluate data in order to build evidence-based approaches to TD training and pedagogy and to spur innovation at the institutional level in order to support team science that can solve complex global problems.

Limitations. There are several limitations that should be considered. First, because open-ended focus groups were used, we cannot be certain that themes were absent simply because they were not reported. This was a limitation we accepted because it was an exploratory study and our goal was to gather the widest range of possible themes. Hopefully our results will contribute to the future development of standardized measures. Second, this was a problem-focused TD training program with a small sample size, and thus may have limited generalizability. Third, due to the

funding parameters of the training program (3–5 students each year for 3 years), sequential cohorts were enrolled in the study over three years, rather than enrolling all students at one time point. Thus, by the third cohort, the program was more refined and the team had resolved some of the logistical and scheduling barriers noted in year one, but the core structure of the program remained unchanged. Finally, five years is a relatively short time, and only a third of the students have now completed their training. However, this study may be the first truly prospective evaluation of a TD doctoral program and we plan to follow students and faculty over 10 years.

Conclusion

The findings of this study provide important implications for others considering involvement in TD training programs. It will be important for TD team leaders and their institutions to attend to faculty concerns about the barriers to participation in TD research and education, particularly concerns about advancement, the perceptions of TD by colleagues, and the degree of commitment required by participants. Leaders can use examples of existing higher education TD programs as roadmaps for developing TD teams and training programs and encouragement to persist despite anticipated barriers. As complex health and global problems continue to be exposed, the unleashed potential of TD team science and the importance of carefully designed TD doctoral programs are increasingly apparent. Continued efforts to build an evidence base to understand the effectiveness and impact of various components of TD education are needed.

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Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the fact that they contain personal identifiers; but they are available from the corresponding author on reasonable request with additional IRB approvals prior to sharing.

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Additional information

Competing interests: The authors declare no competing financial interests.

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