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Using Discourse Analysis to Study a Cross-Disciplinary Learning Community: Insights from an IGERT Training Program

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ABSTRACT

A major challenge for fostering integrative cross-disciplinary collaborations at the graduate level arises from the divergent exposure and training of students from uni-disciplinary graduate programs. In this report, we present the design and preliminary analysis of an experimental forum to facilitate cross-disciplinary discourse within a NSF-sponsored Integrative Graduate Education and Research Traineeship Program (IGERT) at Rutgers. This forum brings together IGERT Graduate Training Fellows and faculty from four diverse graduate programs in the engineering area and four related programs in life sciences and physical sciences for structured seminars and interchanges. Our report offers methodological and analytical tools grounded within a conceptual framework for promoting discourse that integrates content across diverse disciplines as well as across levels of inquiry. Both the theoretical framework and the research tools may be valuable to others seeking to develop integrative training environments for coalescing learning communities between engineers and their collaborators.

Keywords: learning communities, discourse analysis, cross-disciplinary, integrative education, graduate education, IGERT, STEM
I. INTRODUCTION

A. Overview
Current thinking about education in science and technology for the 21st century emphasizes (i) the increasingly cross-disciplinary and interdisciplinary nature of research[1–4] and (ii) the importance of learning communities that foster both peer-to-peer and peer-to-expert discourse[5]. The former is the impetus for major initiatives such as the National Science Foundation’s Integrative Graduate Education and Research Training (IGERT) programs (www.igert.org; www.nsf.gov/crssprgm/igert/intro.jsp). The latter is the subject of a body of research (references in what follows) about discourse-based and communicational approaches to cognition that provides a theoretical framework for analyzing the effects of implementing programs such as IGERT.

Prior studies of discourse-based learning communities have focused on primarily uni-disciplinary contexts and GK-12 education [6–9] and on professional degrees such as the MD [10]. There are several ways in which these educational settings differ from graduate education in STEM [STEM = science, technology, engineering, and mathematics] fields in general and IGERT programs in particular. First, whereas both GK-12 and post-baccalaureate professional-school programs are typically built around a well defined curriculum delivered in defined sets of courses and group practicuums, doctoral graduate education in science and engineering is much more research/experientially based and also individualistic (i.e. fewer required courses and virtually no course work after the first 2–3 semesters, with the remaining several years devoted almost solely to one’s own thesis research). Second, in uni-disciplinary settings, the focus of the learning community is essentially homogeneous (i.e. the subject matter, terminology, methodology, norms, culture, etc. are held common by all within the community). In contrast, in IGERT programs and other cross-disciplinary environments, graduate students are acquiring knowledge not only in the core-discipline of their
home graduate program (similar to what occurs in uni-disciplinary contexts), but also in (i) disciplines that they themselves are exploring as part of their own cross-disciplinary research and (ii) disciplines that are even farther a field from their own research.

This paper reports our experiences and insights in developing a discourse-based approach to cognition that addresses these unique attributes of the increasingly interdisciplinary landscape of graduate doctoral education in STEM fields. We have designed a new, experimental program called COLTS (abbreviation for Community of Learners and Thought Shapers), as an integral part of the NSF IGERT on “Integratively Engineered Biointerfaces” at Rutgers University (www.igert.rutgers.edu). Within COLTS, we have developed and deployed an experimental forum, which we call the IGERT Research Interchange Forum (IRIF), that brings together Graduate Training Fellows (GTFs) and faculty from four diverse graduate programs in the engineering area and four related programs in life sciences and physical sciences for structured seminars and interchanges to facilitate discourse and learning. Integral to our development of COLTS is the collaboration with colleagues at the Robert B. Davis Institute of Learning (RDBIL) of the Rutgers Graduate School of Education (www.gse.rutgers.edu/rbdil/site/default.asp), who have developed a body of longitudinal research in the field of middle school and high school mathematics education [11], as well as best practices in the education of mathematics doctoral students [12]. The composition of the COLTS learning community is summarized in Figure 1.

B. An NSF-sponsored IGERT program as the setting for a cross-disciplinary discourse-based learning community

The Rutgers IGERT on Integratively Engineered Biointerfaces is the research-centric educational context for our studies on discourse-based learning. It is one of approximately 125 IGERT programs supported by the NSF since 1997 (complete directory at www.igert.org). The IGERT mission is to foster innovation
and catalyze institutional changes that integrate graduate education and professional training with the doctoral research experience (further information at www.nsf.gov/crssprgm/igert/intro.jsp). Within the IGERT umbrella, some programs feature newly created Ph.D. degree programs in emerging fields, while others, like ours, are “degree-plus” – with students pursuing a Ph.D. in an existing “home” graduate program. Each institutional IGERT is unique in the sense that each program focuses on a novel or emerging research area reflecting the research expertise of the respective local institution.

The research focus of our IGERT program at Rutgers, “Integratively Engineered Biointerfaces” (IEB), encompasses the interfaces and interfacial phenomena that occur at the confluence of the three major constituents of biological substrates: cells, biomolecules (extra-cellular and sub-cellular entities, e.g. proteins, DNA, etc.) and biomaterials (synthetic materials such as typically found in surgical implants, etc.). Research at this confluence typically spans size scales from nanosystems (e.g. internalizable ligand nanocarriers; intracellular protein/nucleic acid complexes) to microsystems (e.g. tissue engineering scaffolds; bioreactors for stem cell engineering). The many and varied research activities in biointerfacial science and engineering provide both fundamental knowledge and enabling technologies that can spawn advances in areas such as biomimetic materials, biomedical devices, biosensors and actuators, rehabilitative medicine, drug delivery, and gene- and cell-based therapies.

Our IGERT program spans three disciplinary areas and brings together students and faculty from eight diverse graduate programs – four in engineering and two each in life sciences and physical sciences – and offers an array of inter-related educational, research and training initiatives. Additional information is available at www.igert.rutgers.edu, and a new multi-disciplinary curriculum on integrative biointerfacial engineering has also been described in further detail[13].
Three successive cohorts of Graduate Training Fellows (GTF’s) have joined our IGERT program over the past three years (2004–6), yielding a total of 26 GTF’s to date. Of these, 16 (61%) are in engineering disciplines, 7 (27%) are in life sciences, and 3 (12%) are in physical sciences. Within engineering, 10 students (38% of total GTF’s) are currently enrolled in Biomedical Engineering (BME), which is also the IGERT’s administrative home/host department. Among the GTF’s in engineering, two sub-populations exist: those whose research is based in cellular and tissue engineering (6 of 16), and those who focus on engineering of biomaterials and biological substrates (10 of 16).

C. Context, motivation, and objectives for developing a program of discourse-based learning in an IGERT setting:
As with doctoral education in all STEM fields, the chief activity of graduate students in our IGERT is the active participation in a research group where they learn the intellectual constructs and the practical methodologies of doing research their chosen field. Although accompanied by some advanced coursework at the outset, it is this research experience, culminating in the generation and defense of a body of original research (the thesis dissertation) that occupies the majority of the graduate student’s time and effort and chiefly shapes the student’s education and training.

In addition to learning the specific subject matter and methodologies of a particular body of knowledge (e.g. biomedical engineering, molecular biology, chemistry) and of a sub-specialty (e.g. tissue engineering, molecular pharmacology, polymer synthesis), the chief activity of graduate students in STEM fields is to learn how to engage in research – how to “do science” or “do engineering” and to join the community of Ph.D.–level scientists to which their research advisors already belong. Thus, these graduate students are in the process of becoming acculturated to the knowledge community of professional researchers, which makes them members of what Bruffee[14] has termed a
transition community. This view of cognitive development reflects a sociocultural perspective whereby “as learners participate together in a broad range of joint activities and internalize the effects of working together, they acquire new strategies and knowledge of the world and culture”[10].

Advanced coursework and laboratory research, by themselves, may not be sufficient for graduate students to acculturate fully into the community of Ph.D. level scientists, particularly in cross-disciplinary fields, because those two activities may not constitute a broad enough range of activities. A primary activity of professional researchers is to disseminate the results of research and communicate the relevance and implications of the findings to future research and commercial applications. The IGERT Research Interchange Forum (IRIF) was designed and implemented to provide the Graduate Training Fellows with opportunities to engage in this aspect of the professional research community and its culture.

In presenting theoretical connections that address the convergence of language and education, Edelsky, Smith and Wolfe[6] observe that learning environments both allow for and are constituted by the discourse that occur within them. Therefore, the IRIFs not only serve the purpose of providing opportunities for the Graduate Training Fellows to disseminate their research findings, but also enable them to observe, experience, and assimilate the norms and values of the professional community those GTFs aspire to join. With regard to interdisciplinary communities in particular, Klein [15] has noted that “repeated interactions build up common language, sensitivity to disciplinary assumptions, and respect for each others’ disciplines.”

Thus, we are fostering a transitional community of interdisciplinary engineering graduate students with the intentional aim of inducting them into what situated learning theorists[16–18] refer to as a “community of practice” [18], where they
engage in tasks, use tools, and share values and beliefs about academic work with their faculty mentors. This community, which we call COLTS, for “Community of Learners and Thought Shapers”, exists within the context of our IGERT program and is specifically designed to augment the larger, less intentional, and more uni-disciplinary communities of practice in which the students find themselves as members of their primary research groups and home graduate programs. The overarching objective of COLTS is to equip students with knowledge of the cultures, languages, methodologies, and tools, that they will need as successful professionals engaged in cross-disciplinary and integrative work in interfacial bioengineering.

D. Structure and activities of the COLTS community: The IGERT Research Interchange Forum “IRIF”.
The primary discourse–based learning activity of the COLTS community is our “IGERT Research Interchange Forum” (IRIF). The IRIF brings together the Graduate Training Fellows (GTFs) and faculty from the IGERT’s eight diverse graduate programs in the life sciences, physical sciences, and engineering for semi-structured seminars and interchanges focused on the biointerfacial science and engineering research themes of the Rutgers IGERT program.

During our IGERT’s inaugural year, two foundational activities preceded the IRIF configuration that is the focus of this report. We began by assembling the first cohort of nine GTF’s to share summaries of their research using only a single PowerPoint slide and about three minute presentation. These initial IRIF’s served to build community among the GTFs as well as inaugurate them to methods of effectively summarizing one’s work in a way that research professionals often do. The one–slide summary activity was followed with monthly IRIF’s presented by IGERT faculty and attended by GTF’s and other IGERT faculty. Time was typically split ~85:15 between presentation and ensuing discussion, and there was little or no intentional facilitation to encourage GTF participation. The objectives were
simply to bring together the nascent IGERT/COLTS community of graduate students and faculty and to introduce some of the major research themes of engineered biointerfaces to the group.

Following these foundational IRIF’s, we transitioned to the student-led IRIF’s that form the basis of our research: The IGERT GTF’s take turns presenting semi–formal talks using PowerPoint presentations about their own specific research activities, which are then followed by a question & answer period open to all the other GTF’s and faculty members in attendance. The goal is to have a presentation to discussion ratio of about 50:50, with the GTF’s participating actively in the discussion period, which is intentionally facilitated to foster the development of the transitional learning community.

We hypothesize that the student presentations and ensuing facilitated discussion periods provide three distinct leaning opportunities that relate to the development of educational and communication skills for cross–disciplinary research.

(1) The presenting GTF gains experience in communicating about his/her research to a diverse audience from other fields.
(2) The presentation exposes the attending GTF’s to new and cross–cutting research that is within the IGERT’s biointerfacial science and engineering focus, but beyond the student’s individual home disciplinary backgrounds and/or specific research areas of expertise.
(3) The discussion period following each talk provides a setting in which the GTF’s engage in facilitated discourse with peers and with others of varying levels of expertise.

The IRIFs present the presenters and the audience with two classes of challenges, Learning Challenges (LC) and Dissemination Challenges (DC), which should be considered as related and dynamically evolving dimensions of learning. Basically, the presenter primarily encounters dissemination challenges (DC), the audience
addresses learning challenges (LC), while the discussion period provides opportunities for addressing both LC and DC. Moreover, during the discussion period, as they speak and listen and observe, the GTF’s are learning and internalizing the thought processes and world views of research scientists and engineers, such as how to discuss one’s work with one’s colleagues and how to plan, evaluate, and manage one’s research program. In short, through the discourse of the IRIF learning community, the students are learning how to “do” science and engineering as aspiring doctoral-level investigators and to address the challenges and opportunities of working in a rich cross-disciplinary context.

II. EXPERIMENTAL FRAMEWORK AND METHODOLOGY

A. Research Overview:
The IRIFs theoretically provide many opportunities for GTF’s to interact across disciplines and across levels of expertise and to build skills that address LC and DC. To track the resulting discourse, we focus primarily on the discussion period of the IRIF’s, where examples of LC and DC can be directly observed in the discourse. (This is in contrast to analyzing the talk itself, where videotape data affords direct evidence of the DC of the presenter, but little about how the audience members are addressing the LC).

We begin by investigating the relationship of discourse patterns and content to the relative proximity of each attendee’s “home” graduate program and discipline to that of the presenting GTF. Six different categories of relative proximity were defined for the participants from the audience:

- Same research group as presenting GTF (SRG)
- Closely related/collaborating research group in same graduate program (CRG)
- Same graduate program but not a related research group (SGP)
• Graduate program of presenter’s cross-disciplinary advisor and group (XDA) (note: active cross-disciplinary advising and research is a key component of our IGERT program
• Other graduate programs in same discipline as presenter (SDIS)
• Other graduate programs in different disciplines (DDIS1, DDIS2)

Only the first, and possibly the second of these categories would be represented in a typical research meeting of each GTF’s primary research group, whereas all are routinely represented in each IRIF. Moreover, given the uneven distribution of GTF’s across disciplines, with the most students in BME and the fewest in Physical Sciences, some talks, overall, may seem overall more “proximal” (e.g. when biomedical engineers present) and some inherently more “distal” (e.g. when physical scientists present). Thus the IRIF’s present a rich and varied landscape of cross-disciplinary contexts for our research. Our first approximation is that the greater the difference in disciplines and areas of study, the greater the potential for significant learning and dissemination challenges – and also, the greater the potential for fruitful cross-disciplinary discourse and cross-fertilization of ideas, provided the communication barriers are adequately reduced.

The research questions that we are investigating include:

1. What differences, if any, are there in the nature of questions asked by members of the community in fields proximal to that of the presenter as compared to those posed by members in distal fields?
2. Do certain discourse patterns catalyze sustained and cross-fertilized discussion among members of the community, and which members of the community more frequently initiate them?
3. What are the particular roles, if any, of (i) the IGERT facilitators and (2) other faculty members in promoting discourse and the addressing of leaning and dissemination challenges (LC and DC) of the GTF’s?
4. What, if any, demonstrable outcomes of the IRIF’s have occurred to date?
B. The IGERT Research Interchange Forum, an embodiment of a discourse-based activity for a cross-disciplinary learning community

The IRIF’s that are the focus of this study – i.e. those featuring a student presentation followed by facilitated discourse – are held approximately every 3 to 4 weeks throughout both academic semesters and several times during the summer. They are intentionally held in spacious conference rooms with large conference tables and layouts that encourage group discourse. They also are intentionally scheduled for the mid-day instructional period (80 minutes), and include an informal sandwich buffet lunch, which is set up about 15 minutes ahead of time so that those who can do so may arrive early for informal conversation and networking.

All IGERT GTF’s attend, with rare, prior-approved, exceptions made for schedule conflicts. The presenting GTF is expected to invite his/her primary thesis advisor and cross-disciplinary IGERT advisor and to recruit at least two other faculty members. The GTF’s are also encouraged to invite postdoctoral fellows and graduate and undergraduate researchers from their groups. Faculty attendance at these IRIF’s averages about 4 or 5 and ranges from about 3 to 8. This significantly higher proportion of GTF’s to faculty (~3:1 or better) is intentional – to promote GTF participation in discourse by creating a GTF-centric environment while also enabling GTFs to interact with faculty beyond the students’ usual research spheres.

The focus of the IRIF sessions is on the research presentation and the discussion that follows. When there are colleagues from the presenter’s research group, new faculty, or other guests, brief introductions are made at the outset of the forum. Other IGERT announcements and programmatic matters are generally dealt with elsewhere or kept to a bare minimum.
The GTF presenter for each IRIF is asked to prepare about a 20–25 minute talk, with slides, that should include:

(1) a description of the background and motivation for the research – including explanations of key terminology and concepts that may be unknown to extra-disciplinary members of the audience

(2) the presentation of a key research nugget – i.e. a recent research accomplishment and/or a nascent research aim, new results, hypotheses, proposed experiments, etc.

(3) an assessment of the research horizon, including future experiments planned, questions that the GTF may want the audience’s help with (e.g. methods and software recommendations for statistical data analysis, access to particular spectrometers, cell lines, etc.), and some projections about the anticipated roadmap to publications.

An overarching goal is that the presenting GTF consider the highly diverse backgrounds and experience levels of the COLTS/IRIF audience. In comparison to a talk aimed at the presenter's own research group, the challenge in this setting is to explain the research to the uninitiated while continuing to engage the experts.

The IGERT Program Director, co-Director, and Program Manager are responsible for convening each IRIF and moderating and facilitating the discussion, fulfilling the role of a coach in the transition community. This includes ensuring a flow of conversation and seeding it as needed so that group discussion proceeds, often by posing a pivotal “why” question to the presenter or an audience member [10].

The body of research that we present in this study is the cumulative result of fifteen IRIF’s – each featuring a research presentation by a GTF’s followed by a facilitated discussion period – that occurred over Year 2 of the IGERT program. During most of this period, our complement of GTF’s numbered 16 (Cohorts 1 and 2), and grew to 25 with the admission of Cohort 3 students.
C. Methodologies for Tracking Discourse and Related Learning Outcomes

1) Overview: Our primary data-gathering instrument is videotaping. Each presentation and its discussion period are recorded in their entirety, using experienced videographers, with subsequent transference to CD-R for iterative viewing and analysis, as will be described further in the following section.

As powerful and comprehensive as videotaping is, however, it captures only the contributions of those GTF’s who participate verbally in the IRIF’s. Listening is also a form of participation and learning. Therefore, we also administer a brief questionnaire at each IRIF with a combination of Likert scale and short answer questions. This questionnaire is designed to serve several purposes relating to both the formal presentation and the discussion period. With respect to the latter, two questions are of particular interest in the context of this research:

(1) Did someone ask a question or offer a comment that helped you understand the presentation better? If so, what and why?
(2) What was the most interesting or informative part of the discussion that followed the talk? Why?

Replies to these questions are correlated with the videotape analyses to corroborate and contextualize the emergent discourse patterns observed.

After the first 13 IRIF’s, we also administered a retrospective questionnaire that posed short answer and open-ended questions about (i) what GTF’s liked and did not like about the IRIF’s, (ii) what specific outcomes they may have experienced, and (iii) how the IRIF’s compared to their uni-disciplinary research meetings with their primary advisors. Analysis and research is on-going, and initial findings germane to learning communities/COLTS are reported in the Results and Discussion section below. Full-length questionnaires are available upon request from the corresponding author.
2) Research design and video data analysis: Our research design was developed through partnership with the Robert B. Davis Institute for Learning at Rutgers Graduate School of Education. The rationale for this design is based on two decades of longitudinal and cross-sectional research using video data to study the development of learners’ mathematical ideas[11, 19, 20]. Among the outgrowths of these research studies has been the evolution of an analytical model for using video data to study developmental thinking in mathematics learning [21]. The richness of video data, along with the need to study learning in the context in which it occurs, makes that technology vital to other research frameworks, such as Interaction Analysis [22].

The salient point is that videotaping the IRIFs allows for iterative and attentive viewing of the videotaped record for researchers to document evidence of how discourse proceeds. Emerging from this iterative and objective study of the actions of the discourse community are patterns that may shed light on how learning is achieved. Rather than begin with a priori assumptions of what patterns are expected to occur, generalizations about what actually does occur are built from observable empirical data, and theories and conclusions are held accountable or “grounded” in those data [23, 24]. As noted by Jordan and Henderson [22], the result of using a grounded-theory methodology is that “accounts of methods cannot be fully separated from accounts of findings, and that the best way to show methods is with instances of the actual work.” Hence, in the description of our methodology that follows, we illustrate our procedures with examples from the body of videotaped data and demonstrate how our analytical framework has emerged in this process.

We begin by scanning the videotape/CD and noting the time markers for the major segments of the IRIF e.g. announcements or special business, beginning of presentation, end of presentation, and beginning of Q&A/discussion period. Within the discussion period, we also look for, record the time, and briefly
annotate: (1) natural pauses or silences, (2) facilitated transitions – e.g. if/when the moderators need to quiet a side discussion or to limit an increasingly detailed discussion of one topic and to call for new questions, (3) clearly pedagogical contributions by the COLTS facilitators and/or the presenter’s advisor, and (4) any lengthy digressions and “monologues” by the presenter and/or others.

This initial, somewhat cursory documentation is similar to the creation of the “content log” in IA [22] and is less detailed and descriptive than the “describing the video data” catalog suggested by Powell et al [21] at this stage. These time markers serve as guides to locate relevant sections in subsequent re-viewsings of the tape for study, annotation and/or full transcription, and analysis.

3) Tracking discourse flow and analyzing participant interchange in a large and diverse group: development of the “Graphical Record of Discourse (GROD):” Our main challenge was to find a way (i) to document the flow and content of discourse among, on average, 20 or more participants in any given IRIF and (ii) to analyze this discourse according to attributes/variables of the learning community – in this case the disciplinary proximity/distalness of participants to presenter as discussed above. Toward this end, we have developed a protocol, a graphical layout/matrix, and a symbolic notation, inspired by some examples in Interaction Analysis [22]. We call this a “Graphical Record Of Discourse” (GROD). The GROD is a two-dimensional plot of the discourse flow, showing its progression with respect to the group attribute/variable under study on one axis and time on the other.

A portion of a GROD for this research is shown in detail in Figure 2, and three complete GROD’s are shown in Figure 3 (at a much lower resolution of detail). Interpretation of GROD’s will be discussed in Section III. Here, we describe how they are constructed:
First, the time axis is constructed (in this illustration, on a scale of 10–15 second intervals). The previously generated content log is consulted to locate the major transitions of the discourse flow (e.g., beginning and end of discussion, natural pauses, extended digressions, and facilitations). Spaces are inserted on the time axis at these points to segment the discourse and provide easy to see reference points/markers. Brief descriptive comments from the content log are annotated at each transition.

Next, the attribute axis is constructed with intervals or “bins” corresponding to the qualitative, semi-quantitative, or quantitative descriptors of the primary attribute being studied. In this case, the attribute is the disciplinary proximity of attendees to speaker, and there are seven categories/“bins”, ranging from same research group (SRG) to different research groups in different disciplines (DDIS1, DDIS2) as defined in Section II.A above.

Adjacent to the attribute labels, this axis is further annotated with a bar graph/histogram that graphically represents the composition of the discourse community with respect to the attribute categories. This is accomplished by assigning each attendee a unique i.d. code and symbol and placing it in the appropriate bin. The different symbols, together with the i.d. codes selected, help to describe additional attributes/variables of the community and to distinguish them graphically. For example: (i) faculty are represented by ovals and students by rectangles; (ii) the on-going members of our COLTS community—(i.e. the IGERT GTF’s and their primary and cross disciplinary faculty advisors) are represented by shaded shapes and visitors and occasional attendees by non-shaded shapes; and (iii) the GTF i.d. code includes the Cohort number (1,2, or 3).

At the far end of the attribute axis and histogram, an additional bin is added, to account for the dual roles of the IGERT/COLTS facilitators. This latter bin is used for tracking their explicitly pedagogical and facilitating
roles during the IRIF discourse. They are also assigned to the appropriate proximity bin for their particular departmental/disciplinary affiliation, which is appropriate when they are asking research-focused questions just like any other faculty members.

For this particular research, a second dashed line, parallel to the time axis, has been inserted after the first two attribute categories/bins, SRG and CRG. Attendees in these two more proximal categories, closer to the time axis, would be likely to attend a “home” or uni-disciplinary research group meeting of the presenting GTF’s primary research group – whereas those in the more distal categories would not. Thus, this boundary helps to delineate the additional disciplinary diversity that is introduced by the IGERT program and experienced in the IRIF’s.

With the construction and labeling of the axes complete, the GROD graph is then generated while the videotape is viewed (in a stop/start fashion): When an attendee speaks, his/her id code and symbol is placed at the appropriate intersection of time and category/bin. Lines and arrows are then drawn to indicate the direction and time flow of discourse among attendees. When the discourse is clearly directed to the group as a whole a starburst symbol is substituted for the circle or oval, and no arrows are drawn. Dotted lines enclose segments of rapid interchanges and simultaneous interjections of more than one individual.)

Thus, the completed GROD’s yield diagrams marked by wave-like patterns that represent conversational flows and the extent and nature of interdisciplinary talk within them. Each GROD, like the examples in Figure 3, is an information–rich graphical record and a unique signature – somewhat analogous to an infra–red spectrum of an organic compound or a person’s electrocardiogram – that can be read, interpreted, and compared with others.
The major divisions (spaces) on the time axis show the segmentation of the IRIF session as defined by the major natural and facilitated transitions observed in the tape/CD (transcription).

The frequency of the waveforms (time axis) represent the pacing of the discourse (short remarks vs. expansive ones; clusters of many short exchanges vs. one or a few brief remarks followed by more lengthy discussion.)

The amplitude of the waveforms shows magnitude of the cross-disciplinary engagement (the higher the amplitude, the greater the cross-disciplinarity and vice versa).

The symbols and i.d. codes indicate which members of the discourse community actively participated in the discourse (faculty or students, IGERT GTF’s or guests, more experiences or newer cohort, etc.). Additionally, comparison of the symbols appearing in the GROD with all those listed in the bar graph easily indicates what proportion of attendees speak up or only listen and whether some GTF’s participate more frequently on average than others.

As will be presented in Section III, our observations to date show that certain types of discourse patterns have signature wave forms. Our GROD methodology serves to identify those patterns deserving deeper analysis of the content to understand further the contexts critical to learning.

4) Capturing the essence of the discourse: key words, paraphrasings, brief verbatims: To describe and classify the discourse further, key words, paraphrasings, and, occasionally, brief verbatims are jotted down in a field adjacent to the GROD flow diagram. This is illustrated in Figure 2B. The textual record thus generated supplements the graphical record with cues about the
content of the discourse. These, in turn, assist the analyst in subsequent study and coding of the IRIF, and to target portions of the discourse record for further detailed study and, as needed, make complete transcriptions of selected segments.

D. Studying and coding the discourse: Iterative viewing and grounded analysis:

The next steps studying the IRIFs represent a significant transition in the analytical methodology, i.e. from objective tracking of who is speaking, along with predominantly objective high-level sorting and analysis, to the development of a coding strategy. Per the tenets of grounded theory [23, 24], we strove to identify what to code for without imposing any significant a priori judgments or conditions about the discourse and let the coding emerge from the data itself.

From our iterative viewing and grounded analysis of the videotapes, we defined two major descriptors, “type of discourse”, and “scaling tendency of discourse”. These are both generalizable properties, occurring irrespective of the specific subject matter of each IRIF. These properties are described in more detail immediately below, along with their coding abbreviations. The next step in constructing the GROD is to add these codes. This is illustrated in Figure 2C, in the fields labeled ”type of discourse” and “scaling of discourse”. Also shown in Figure 2C is additional coding labeled “helpful discussion” and “interesting/informative part” that indicates which segments were so identified (and by what classifications of GTF’s) in the questionnaires administered after each IRIF.

1) Type of discourse: We have observed and categorized eight different types of discourse and three additional facilitation modes in the IRIF’s. The table of types, codes, and examples is shown in Table 1.
Table 1: Types of discourse observed in IRIF’s

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<th>Code and type</th>
<th>Characteristics</th>
<th>Example(s)</th>
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| QS Simple inquiry | Short, to the point; seeking specific information and generally generating a short answer in return  
Often starts with “How do you...?” or “Do you...”  
More often by audience than by speaker | “Did you do those experiments in distilled water, or phosphate buffered saline, or serum?” |
| QC Inquiry for clarification/facilitation | Also short and to the point and generally generating a short answer in return  
Used by speaker in answering questions; also by facilitator(s) and audience members | By speaker: “Does that answer your question?”  
By facilitator or audience member: “Are you referring to what you just presented about the co–cultures, or to the earlier work with just the fibroblasts alone?” |
| QE Open–ended inquiry | Invites more than just a simple answer;  
Sometimes the question is not entirely clear; may require some dialog to clarify intent of question | “I’m not sure I understand why you use transmission electron microscopy as well as light microscopy; what does it tell you that light microscopy does not?” |
| RS Simple answer | Short; matter of fact; usually does not invite a reply –  
More often by the speaker/presenter than by audience members – except in the midst of an extended discussion, where audience member may contribute | “We do everything at physiological temperature except the time–lapse microscopy, which we are doing at room temperature until we get our new thermostated stage.” |
<p>| RE Explanation/elaboration | More expansive than a simple answer, but still related to a question, and basically factually–based, | “In this protocol, note that we do two assays so we can distinguish necrotic and apoptotic cells. This is important because there is an inflammatory response to necrotic cells, but not to apoptotic ones.” |
| CO: Corroboration/comment | Usually offered by individuals other than the presenter; consists of – affirmations and asides that do not divert the discourse | “The post–doc in our lab is also trying to use that protocol. He is having the same problem with cardiomyocytes that you are having with fibroblasts.” |</p>
<table>
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<tr>
<th>Code and type</th>
<th>Characteristics</th>
<th>Example(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HS</td>
<td>Hypothesizing/Speculating</td>
<td>Seeks to expand content or context of inquiry and typically involves some speculation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>May begin “so would you say that…” or “in that case could you…” (question) or “We believe that…” or “We are predicting that…” (statement)</td>
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<tr>
<td>Ar/As</td>
<td>Argumentation/Assertion (argumentation in the rhetorical sense, not the confrontational)</td>
<td>Often about the data analysis and interpretation, i.e. “defense” of the basic assumptions and/or the findings. Sometime also about how research relates to motivation and “big picture” goals.</td>
</tr>
<tr>
<td>F-inf</td>
<td>Facilitation: Informational</td>
<td>Faculty member, or more experienced GFF providing important information or interpretation (information not expected to be known by presenter or others in the audience)</td>
</tr>
<tr>
<td>F-ped</td>
<td>Facilitation: Pedagogical</td>
<td>Comments or questions that intentionally draw out a student to expand on an idea, encourage more cross-disciplinary or integrative thinking, etc.</td>
</tr>
<tr>
<td>F-proc</td>
<td>Facilitation: Procedural</td>
<td>Typically offered by one of the facilitators, and includes call for questions from GTF’s, stopping of side or simultaneous discussions, etc.</td>
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Subsequent to having analyzed the videos and observed these discourse types, in the course of doing a literature search, we noted that our categories are analogous to those discussed by Palincsar [10] quoting Abercrombie [25], who commented on “the significance of elaboration, interpretation, explanation, and argumentation in promoting learning.” There appear to be clear parallels (and
overlaps) with our categories – for example RE, QC, CO, and F-inf with elaboration and explanation, QE, H, Ar/As, with interpretation, Ar/As with argumentation, etc.

2) **Context or scaling tendency of the discourse:** This property relates to where the discourse fits in the landscape of activities that comprise the experience of doing research. While this attribute clearly exists on a continuum and the assigning into classifications sometimes subjective, we nevertheless did observe a clustering into three basic groups: tactics (T), strategy (S), and big picture/background (B).

Tactical discourse (T) focuses on factual information and clarification about the research being reported upon (“Are you using a fragment of fibronectin or the whole thing?”; “What do you mean by apoptosis?”), whereas big picture discourse (B) addresses fundamental background facts and assumptions (“Are you interested in promoting cell growth, or cell movement, or both?”), and how the experimental work relates to the big picture, motivation, and long term goals (“If you are going to make a biosensor for real-world applications, how will you keep your cells viable and package the device?”). Between these respective “trees” and “forest” extremes are issues of strategy (S), e.g. hypothesis formulation and testing, design of experiments, decisions points about which of several avenues of inquiry to pursue, etc. (“With that test alone, how do you tell the difference between a positive result from a few cells with high activity and a lot of cells with moderate activity? Won’t you need to do something else, as well?) Table 2 summarizes these three categories of scaling tendency of discourse.
<table>
<thead>
<tr>
<th>Dimension</th>
<th>Characteristics</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>T, Tactics</td>
<td>Focuses on the specific research: what the presenter is doing on a day to day basis: It is the discourse that relates to what the presenter reported on doing Therefore, it usually includes: Experimental methods Data analysis methods Data reduction methods, i.e. plots, micrographs</td>
<td>What is F-star parameter, and what does it relate to? Are you talking about the whole nerve or just the axons?</td>
</tr>
<tr>
<td>S, Strategy</td>
<td>Focuses on experimental design; analysis and interpretation of results; asserting what the results say about the hypotheses and defending this interpretation; brainstorming about other interpretations</td>
<td>If you get a strong signal, how do you tell the difference between a few cells with high activity or a lot of cells with moderate activity? You are assessing cell maturity and function by albumin turnover; what other approaches could you use? What else is it critical that the cells do? You are using collagen, which is based on a natural, proteinaceous substrate. Did you consider non-biomimetic, synthetic biomaterials, such as silicones and polyesters?</td>
</tr>
<tr>
<td>Dimension</td>
<td>Characteristics</td>
<td>Examples</td>
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<td>-----------</td>
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<tr>
<td>B Big-picture/Background</td>
<td>Focuses on context and/or motivation for the research, including: What it seeks to contribute in terms of basic knowledge and/or technological outcomes Longer-term goals, specific outcomes (new therapies, implants, biosensors, etc.)</td>
<td>Could/how could the DNA-based hydrogels be made sterile for surgical implantation? So your transistor based sensor does not require derivatizing the DNA with fluorophores. But DNA chips are pretty well established. Why do you think this will be an advantage? What limitation/need does this address?</td>
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### III. RESULTS AND DISCUSSION

We examined the totality of summarized observations – i.e. GROD charts, content/context of discourse notes, codings of discourse types, and correlations with questionnaire responses – and we looked for emergent patterns, trends, similarities, and differences across all fifteen IRIF’s analyzed to date. To illustrate our observations, three representative IRIF’s have been selected, and their GROD’s are shown in Figure 3. The proximity/distal distribution of GTF’s, faculty, and other students in attendance is shown graphically in the bar graph/histogram above each in each GROD trace (as described in Section II.C3). Detail not readable in the GROD’s, such as the exact i.d. code for each participant, is not necessary for this discussion. Likewise, complete discourse annotations and codings (like those in Figure 2) are not shown, but paraphrasings and verbatims are included in the accounts that follow – along with discussions from other IRIF’s as relevant. These 3 IRIF’s are briefly described in Table 3.

<table>
<thead>
<tr>
<th>IRIF</th>
<th>Presenter</th>
<th>Topic</th>
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Table 3: IRIF presentations for the three GROD’s shown in Figure 3.
**IRIF** | **Presenter** | **Topic**
---|---|---
A | Biomedical Engineer Integrating from a tissue engineering focus; Cross disciplinary investigations in genomics | Controlled differentiation of embryonic stem-cells into functional hepatocytes: assessment of maturity
B | Biomedical Engineer Integrating from a biomaterials & biomechanics perspective; Cross-disciplinary investigations in neuroscience | Microfluidically generated substrates with durotactic and chemotactic gradients to promote neurite outgrowth
C | Chemist Specializing in physical organic chemistry and spectroscopy; Cross-disciplinary investigations in nanoscale biomaterials and drug delivery/pharmaceutics | Probing the conformational dynamics of micelles and amphiphilic nanoparticles with time resolved fluorescence spectroscopy for drug delivery applications

**A. Discourse flow and patterns – general observations:**
Although recognizing that content analysis is absolutely vital to a complete study, we began by considering what overall similarities, differences, and generalizations can be deduced solely from the 2D graphical analyses of participation patterns, and how these patterns can pinpoint segments for subsequent analysis and comparison incorporating content analysis.

Through analysis of the fifteen IRIF’s to date, as represented by the three GROD’s in Figure 3, we have observed the following:

- Each IRIF discussion period (20 to 30 minutes long) has about 5 to 10 identifiable segments, as delineated by natural pauses and/or facilitated transitions.
- Each IRIF has been found to be a unique ensemble, with different total numbers of segments, different proportions of facilitated and natural transitions, different graphical signatures in the segments (as indicated by frequency and amplitude and type of participant (as described above) and different progressions of these signature elements throughout the IRIF.
- Despite the diversity of discourse across the IRIF’s, certain signature segments appeared in many of the IRIFs. Although varying in specific content and occurring at different times in the respective IRIF’s, these
segments nevertheless had distinctive common characteristics, for example:  .

- low amplitude, indicating discussion only among only most proximal attendees (Ac, Bh);
- high frequency and high amplitude, indicating several short, simple Q’s and A’s, along with symbols indicating contributions from several different GTF’s and faculty (Bb, Cb);
- traces higher than baseline, indicating “side” discussions in which the presenter was not involved (often an explanation by a subject matter expert to one of the GTF’s), (Ba, Bf,Cb)
- dialogs between one of the facilitators and the presenter (Ae, Be), or among the facilitator, presenter and presenter’s primary faculty advisor (Cd)
- active discussions with rapid interchanges among participants and/or people trying to contribute simultaneously (shown with dotted lines in Aa, Ab, Bd, Bh, Cb, etc.)
- explications directed to the whole group, as opposed to dialog between/among individuals (shown with starburst symbols in Aa, Bd, Bi,Cb, Ch, etc.).

As noted previously, the GROD methodology helps to locate these repeating patterns so they can be further studied and compared across the IRIF’s in which they occur.

- On average, about 40 to 60 % of GTF’s attending an IRIF asked one or more questions. The data sets are small and multi–variate, yet there was no evidence of biased correlations of the overall level of GTF involvement with the disciplinary proximity/distalness of the speaker/audience interaction.
- Based on our small datasets, as a disciplinary group, the life scientists appear to have a higher participation rate in relation to the engineers and physical scientists, which may reflect the notion that life science serves as
the unifying foundational discipline of this particular learning community (which focuses on biologically engineered or analyzed systems). However, further research is necessary to probe this possibility.

B. Integrative analysis of discourse type, discourse scaling, questionnaire feedback, and research context:
Additional insights and generalizable trends emerge when analyses of the purely graphical GROD's are combined with the codings of discourse type, and discourse scaling, the specific research context, and questionnaire feedback. With the integrative analysis of these various data sources, we re-examine the preliminary questions posed at the outset:

1) What differences, if any, are there in contributions to discourse by members of the community in fields proximal to that of the presenter as compared to those by members in distal fields?

Differences in Scaling Tendencies: Overall, the scaling tendency of questions posed in an IRIF tends to correlate strongly with disciplinary proximity. Proximal colleagues tend to pose (i) tactical questions (T) about the further development of basic methodologies and protocols and (ii) some strategic questions (S) that focus on experimental design and data interpretation. Thus, the more members of the IRIF audience that are proximal to the presenter, the greater the proportion of the IRIF that may be devoted to these topics. Conversely, the more distal the audience, the greater the scaling tendency toward questions about (i) big-picture/background (B) questions of motivation, anticipated long-term outcomes/applications, background assumptions/facts, etc., (ii) strategic issues (S) about hypothesis formulation and (iii) how specific aims (S) relate to the big picture (B) issues.

For example, in IRIF A – with high proportions of attendees proximal to the presenter’s theme, much of the opening segment (Aa), together with the long “low
amplitude” discourse segment (Ac) were focused primarily on technical issues (T) about the methods to assess maturity of differentiating embryonic stem cells, together with a few low-level strategic comments about how the current protocols might be improved upon.

In contrast, in IRIF C, in which nearly all the audience was distal, the opening question (Ca) went straight to the long-term goal of the work (i.e. better drug-delivery of hydrophobic and labile compounds), and the ensuing several segments remained focused on background and strategic questions about the use of micelles as drug delivery agents. For well over half of the discussion, there were no questions about spectrochemical methods, photophysical models, and data/results to date – i.e. the topics that had comprised the majority of the actual content of the presenter’s talk.

The correlation of higher proximity with fewer questions about strategy and big/picture/background does not mean that proximal colleagues are not interested in these issues. To the contrary, we speculate that it implies that the proximal colleagues have (or, more precisely, think that they have) a lower learning challenge toward these topics and thus less of a compelling need to ask questions and engage in discourse about these kind of questions. Soon after people join a research group, they learn and internalize the big picture/motivation for the research the subsequent and on-going uni-disciplinary research meetings focus so much on the immediate tactical research outcomes that questions of higher scaling tendency are rarely re-visited and discussed. Thus, the IRIF’s provide a unique setting, because these questions are raised by the more distal members of the diverse discourse community, enabling the proximal colleagues to revisit these topics, and to do so in an environment with diverse colleagues well equipped to bring many perspectives to these higher-level questions.
Although this clear correlation of scaling factor and proximity was widely observed across many IRIF’s, there were interesting exceptions to the correlation. IRIF B is an insightful example. As in IRIF A, the presenter was also a Biomedical Engineer and the proximal/distal distribution in the two IRIF’s is quite similar, and very different from that in IRIF C. However, many fewer discourse segments in IRIF B were devoted to discussions in the Tactical (T) scaling tendency than in IRIF A. Instead, much of the discourse focused on (i) background/basic/big picture (B) issues = e.g. fundamental questions about neurite outgrowth Ba, Bg, Bf) and how this related to the overall motivation of addressing spinal cord regeneration after trauma (Bd, Bf); and (ii) strategic questions (S), e.g. how experiments had been designed and results would be interpreted (Bc, Bj).

A possible explanation is that IRIF B was the first IRIF the GTF’s attended about the design of tissue scaffolding for nerve process outgrowth. In contrast, IRIF A was the second IRIF in the same semester on the tissue engineering of embryonic stem cells (ES) into hepatocytes. Therefore, neither proximal nor distal attendees were as familiar with the research in IRIF B than in IRIF A. In other words, the learning challenge (LC) was on average higher in IRIF B than in IRIF A, and this difference was reflected in the higher proportion of questions about strategy, overall goals, etc. Thus, we observe that a tendency to asking strategic and big-picture/background questions also appears to correlate with the magnitude of the learning challenge for all colleagues, including the proximal ones.

Beyond proximity (or distalness), individual styles of inquiry also influence patterns of discourse. Among the questions that frequently catalyze wide-ranging and cross fertilized discussion and overcome the early learning challenges (LC) of distally trained colleagues, are those that simply begin, “I don’t understand” and “Can you explain more about...”. Some GTF’s, regardless of their proximity to the presented topic, may be reluctant to pose such seemingly blunt and provocative
questions. Our observations indicate that a particular subset of GTF’s seems be inclined to ask these questions irrespective of their disciplinary affiliation.

2) What are the particular roles, if any, of (i) the IGERT facilitators and (ii) other faculty members in promoting discourse and the addressing of leaning and dissemination challenges of the GTF’s?

We identified three types of facilitations, as previously summarized in Table 1, Types of Discourse. They are: Informational (F-inf), Pedagogical (F-ped) and Procedural (F-proc)

The intent of Informational Facilitation (F-inf) is to introduce specific information for elaboration of a topic relevant to the discourse, which helps address the learning challenges (LC) of the GTF’s. These facilitations are sometimes offered by the IGERT/COLTS facilitators, but more often by the attending faculty members, and occasionally by IGERT GTF’s and other guest students/post-docs with a particular area of expertise. This informational facilitation is often directed to the group at large, unlike the more Socratic and specific Pedagogical Facilitations (F-ped).

Prime examples of Informational Facilitation (F-inf) occur throughout IRIF C in Figure 3. In segments Cc and Cd, the presenting GTF’s faculty advisor offers background information about fluorescence lifetime methods (“In addition to [GTF’s] work, which is based on making model compounds and obtaining their spectra and measuring lifetimes, another student in our group is pursuing a complementary approach, based on Monte Carlo simulations, to explore related questions of …”); In Cb, one of the IGERT facilitators, a faculty member from the same graduate program but a different research focus, fills in some information about drug formulation and delivery (“[presenting GTF] would not be expected to know this, but in drug delivery circles, pegylation is the standard method for modifying/passivating surfaces”)
Pedagogical Facilitation (F-ped) of discourse is performed primarily by the IGERT facilitators, sometimes naturally assisted by some of the attending faculty who have a particularly strong sense for integrative and cross-disciplinary research and/or commitment to the mentoring of students. Two types of Pedagogical facilitations are observed in the IRIF’s. In the first, IGERT facilitators help the presenters to clarify, re-phrase, or generalize a response or a query, which helps them address their dissemination challenge (DC) (“That’s a good answer in the context of the experiment you just did, but I think there’s a more general question here: Can you comment on...”; “Can you say more about what you are thinking about and why you are asking that question?) IRIF segment Ac (Figure 3) is illustrative: During the first half of this segment, the facilitator interjects two prompts into the presenter’s long explanation/elaboration.

Another mode of Pedagogical Facilitation involves asking questions of the presenter and/or the audience that encourage more cross-disciplinary and/or integrative thinking (“Even though this is the cell biology part of the research (differentiation of embryonic stem cells), you need to approach this like the engineer you are. If you could re-design the system to overcome the transport bottleneck, what would you do?”(in Ae). This latter type of facilitation also can plant the seeds for highly “interesting” and “helpful” discourse segments that occur later (e.g. Bd).

Procedural Facilitation (F-proc), i.e. the moderating of the IRIF, is performed almost exclusively by the IGERT facilitators. Each IRIF discussion period begins with an IGERT facilitator calling for questions from the GTF’s. This Procedural Facilitation is a “best practice” learned during the first few IRIF’s and followed since then. It assures that the IRIF is not unintentionally usurped by faculty interests and agendas that would constrain the time available for GTF’s to participate.
The need for further Procedural Facilitation during the discussion period varies widely.

- Sometimes IRIF discourse flows with little or no subsequent facilitation (e.g. Figure 3, IRIF C).
- In other cases the IGERT facilitators need to play “traffic cop” to acknowledge and call upon in sequence the participants who have questions, and silence simultaneous and side conversations (Aa).
- Facilitation may also be needed to stop a lengthy discussion and to ask the participants to take the discussion “offline” so that new topics can be raised and the opportunities for GTF participation enlarged (“Can we hear from some GTF’s who haven’t spoken up yet? Don’t worry, there are no dumb questions, someone else may be wondering about the very same thing you are” (transition from Ac to Ad)).
- At the other extreme, facilitators may need to step into pauses/silences to call for more questions from GTF’s (Bf) and/or to pose a question themselves during a slow-paced or fragmentary discussion (Bb, Bd).

The over arching goal of these Procedural Facilitations is to encourage broad GTF participation in the discourse community. As will be discussed, these seemingly mundane calls for questions by IGERT facilitators have sometimes elicited questions that prompted the very discourse segments that GTF’s subsequently identified as “most helpful” and ”most informative”.

3) What discourse patterns act as a catalyst for sustained and cross-fertilized discussion among members of the community, and which members of the community more frequently initiate them?

These questions beg prior questions: What constitutes sustained and cross-fertilized discussion? How do we identify it so we can then analyze the patterns that preceded it and the person(s) who catalyze it? The answer is that we first look for GROD patterns that include (i) amplitudes that reach beyond the “uni-
disciplinary” dashed line (i.e. not just among colleagues from groups most proximal to presenter); (ii) involvement of more than just two people (i.e. discussion, not dialog). (iii) some low/moderate frequencies (i.e. not just high frequency indicating only simple questions and answers). Examples include Aa, and Ad, Bh and Bi, and Cb. We then examine the content annotation and codings of these segments to further assess the quality and impact of the discussion.

We did not observe a preponderance of any one discourse pattern immediately preceding such segments of cross-disciplinary and engaging/sustained discourse. Upon closer examination, however, we observed some content threads – often starting much earlier in the IRIF and interspersed with digressions and interruptions. Such an induction period may provide time for GTF’s to mull things over, or actually prompts a further thought/connection (or both), but after such an interlude, there is often a often re-visiting of the topic, at which time the conversation mobilizes into a highly engaged cross-disciplinary interaction.

A prime example of the nucleation, induction/broadening, and mobilization of integrative discourse occurs during IRIF A (Figure 3) – concerning stem cell engineering and in particular how to assess the functional maturity of cells differentiating into liver cells called hepatocytes. A synopsis follows, illustrating the evolution of discourse and the additional factors necessary to sustain such interchanges, ensure that they have broad participation and high scaling tendencies, and promote integrative thinking:

- Early in the talk (Ab), a cell/molecular biologist asked a simple/straightforward question (QS), “Are there layers of cells at different stages of differentiation?”, to which the presenter responded with an extended answer (RE) about the cell markers and three germ layers. The discourse then progressed to another topic, i.e. an extended and highly specialized discussion (Ac), mostly among proximal GTF’s, guest students,
and faculty from the same and closely collaborating research groups, about cell markers for differentiation and when to sort/harvest cells.

- After over 5 minutes on the same topic and with no sign that the end was in sight, one of the facilitators requested that the conversation be taken off-line and called for questions from GTF’s other than cell biologists and tissue engineers (transition from Ac to Ad). A physical scientist GTF then asked a series of three short questions about basic background information, the last of which was if the presenter would be comparing gene expression with that of adult liver cells in diseased states (which related to the big-picture (B) motivation of the work, an extracorporeal liver device). The presenter elaborated and asserted/argued (RE, Ar/As) that a useful line of inquiry might be to study gene expression at the fetal to adult transition.

- A biomedical engineer, one whose research focus is biomaterials/biosensors and not tissue engineering, (and, parenthetically, one of the GTF’s who is usually quiet at the outset of the IRIF but may participate later), then asked a question about the layers of cells in the embryoid body (i.e. relating to the “seed question” from the biologist earlier in the talk), culminating in an inquiry about the “source of liver tissues”. This prompted an exchange between the presenter and the questioner, assisted by another GTF from the presenter’s group, that the goal of the work was not to make a liver tissue, but rather a suspension of liver cells that could be used to detoxify blood (somewhat analogous to dialysis for kidney disease). There was an audible murmur from many people around the room of, “oh, I get it now” (a response that was also reflected in the “interesting question” responses in the questionnaires). [Note: In the parlance of the Maher and Powell methodology, [20, 21, 26] this could be termed a “critical event”]
• There then ensued (final third of Ad) an extended cross-fertilized discussion between the presenter and a Life Scientist covering a variety of mostly tactical (T) questions about co-culturing, staining, etc. As this concluded (transition to Ae), one of the facilitators brought the discussion full circle – and also connected it to the earlier uni-disciplinary discussion of cell markers and cell sorting strategies – by restating the GTF’s questions from the “critical event”, including the one about layers in the embryoid body. The facilitator challenged the presenter and proximal colleagues to “engineer an intelligent embryoid body, to overcome experimental bottlenecks”. A cross-fertilized brainstorming discussion continued at the strategic (S) and big-picture (B) levels for the next several minutes until it was time to close the IRIF.

With respect to which members of the discourse community contribute to sustained cross-disciplinary discourse, we identified three important contributors:

• GTF’s, usually distal ones, asking basic “I don’t understand” and “Can you explain more” questions that prompt elaboration and explanation,

• GTF’s, often distal but sometimes proximal, inquiring about how the experimental work relates to the big picture, and

• the IGERT faculty conveners/facilitators, intentionally asking for clarification of hypotheses and speculation about “out of the box”, alternative ways of approaching research questions

The presence of subject matter experts is critical to provide explanations and elaborations (RE, PS, etc) that can help to satisfy the varied learning challenges (LC) of the members of the community. Hence, the presence of faculty, augmented with the particular knowledge residing with the guest graduate students, post-docs, and certain of the more experienced IGERT GTF’s, is essential. Also necessary are the skilled pedagogical and procedural facilitations (F-ped, F-proc) of the IGERT conveners who capitalize on opportunities to make
connections among treads of the discourse and to raise integrative questions/opportunities.

4.) What, if any, demonstrable outcomes of the IRIF’s have occurred to date? To address this question, a retrospective questionnaire was administered that asked the GTF’s about any benefits they derived from participating in the IRIF’s as attendees/audience. In three open-ended questions, the GTF's were asked to identify (i) specific benefits/outcomes and (ii) less tangible outcomes of attending the IRIF’s and also (iii) to cite insights/experiences that they considered to be integrative and why. (A separate questionnaire elicited analogous feedback from the standpoint of being a presenter). Additionally, in a focus group, GTF’s were also asked to provide constructive criticisms and opportunities for improvement in the IRIF’s. There was 100% response to both data gathering efforts.

- **Specific benefits** from attending the IRIF’s, cited by over 60% of the GTF’s, all focused on learning about experimental methods, protocols, and instruments beyond those which they knew about from their primary research group and home graduate program.
  - Of those GTF’s citing such tangible outcomes, most (over 70%) indicated that they had not yet begun to use any of these new experimental approaches in their research, but that they had had specific discussions/consultations that provided a better idea of what methods would and would not be appropriate. (“I learned about new techniques. I do not yet use any of them. Still, I like the exposure. Maybe I’ll need to use these techniques in the future. Specific examples are x-ray crystal analysis and some surface methods.”).
  - The experimental methods that GTF’s reported they were actually incorporating into their research included: fluorescence microscopy, protocols for cell culture, and new bioinformatics approaches to the analysis of microarray/genomics data.
Among both those who have actually begun to use a new method/instrument/protocol and those who had only consulted/considered it, a consistent theme was that the chief benefit of the IRIF’s was the networks forged with the other GTF’s, thereby affording direct access to these new experimental resources and/or to appropriate non-IGERT colleagues who could provide specific assistance.

- **Less tangible benefits** to attending the IRIF’s were also reported by over 60% of the GTF’s. All of these benefits related in one way or another to the learning challenges (LC) and dissemination challenges (DC) of communicating about research to diverse audiences.
  - While recognizing that the dissemination challenge (DC) is addressed most directly when one is the presenter, GTF’s nevertheless noted that attending the IRIF’s helped to address the DC indirectly, because it gave them a better sense of “what made a good talk versus a great talk” and provided insights about organizing the talk, managing one’s time, presenting data tables and plots that explain the data clearly, etc.
  - Several GTF’s specifically cited benefits from the discussion period after the talk – and how this helped them better to equip themselves both to pose and to answer questions effectively. One GTF reported that with the confidence in asking questions that she acquired from attending IRIF’s, she in turn has catalyzed the research meetings in her home department, which used to have only a stilted and perfunctory question period and now, thanks to her setting an example, are becoming more interactive.

- **“Integrative” experiences** from participation in IRIF’s were reported by (about 35%) of the GTF’s.
• Specific examples included (i)” IGERT GTF’s talking about cell pathways; helpful for me to learn goals and outcomes of drug delivery in a more practical way (bigger picture)”, (ii) “integrating molecular biology and computer simulations; integrating these separate disciplines is bringing interesting and surprising results”, (iii) discussions among fellows from different research groups about statistical analysis of data, and (iv) example of collaboration between biologists and bioengineers for bone biomaterials in IGERT Cohort 1 being instructive for chemists and materials scientists in Cohorts 2 and 3 also planning on integrating a biological perspective.

• Several GTF’s cited the discussion period itself as an integrative experience. “It is interesting to hear people from different departments comment on a presentation and share their perspectives”. “It is nice we are given half an hour for discussion to promote the sharing of ideas.”

5) Additional observations beyond the original research questions:

Learning challenges (LC) and the scaling tendency of discourse: Correlation of GROD segments with questionnaire feedback re: “most helpful” and “most interesting” parts of discussions show that the responses tend to cluster on two to three segments per IRIF. Most frequently cited are segments dealing with (i) “big-picture” (B) questions and (ii) some “strategic” (S) issues, particularly experimental design and hypothesis formation. One such example is the “critical event” described in the synopsis of IRIF A above.

Seemingly tactical (T) GROD segments are sometimes highly cited as well—and by both proximal and distal GTF’s. The majority of IRIF segments so rated deal with how to make quantitative measurements and how to plot data. For example (in another IRIF, not shown) a life scientist presented a plot of a family of curves showing amplitude of a signal versus cycle number for some rt-PCR experiments.
This prompted a discussion that was universally rated – by both proximal and distal GTF’s – as both “helpful” and “interesting”. Questions addressed in the discourse included “What quantity is plotted on the vertical axis?”; “Why do there seem to be two families of curves, on the basis of the onset and slope of the transition?”; “After how many cycles are the data too noisy or suspect?”; and “When you interpret these, do you look at the slope or the final plateau? What does it tell you? Is this a question of kinetics or yield?.

Other examples of discourse segments so cited include (i) how to make mobility measurements in field–effect transistor biosensors, (ii) how to plot living, necrotic, and apoptotic cells in dose–response studies of anti–tumor agents and (iii) how to interpret XRD pole plots of nanocrystalline materials for bone tissue scaffolds. In all of these examples, there is evidence that the students were trying to make sense of both the data and the concepts. In the discourse, they were exploring ideas that were new and engaging.

The most difficult elements of the learning challenge: Our analyses of the IRIF’s, together with GTF feedback from the questionnaires, suggest that the three most difficult elements of the learning challenge are (i) the language/terminology of a discipline, including the treatment and presentation of data, (ii) the need to operate at all three levels of scaling tendency and, (iii) the difficulty of seeing the connections of tactical day to day research findings and long–term/big picture motivation. GTF’s have suggested that these might be ameliorated if the presenting GTF were to disseminate (via the GTF on–line forum) a week or so ahead of the scheduled IRIF (i) a 100–200 word abstract “in plain English” and a glossary of any particularly esoteric terms and (ii) a recent manuscript from the GTF’s research group and/or a major review paper or “citation classic” in the field, for the benefit of those GTF’s who might want to read them before the talk. This initiative – which coincidentally affords the presenting GTF another medium for
addressing the DC – has been implemented for Year 2, now in progress, and the effects of this change will be followed and assessed.

Role of additional factors beside disciplinary diversity in the fostering of cross-disciplinary learning in STEM research communities: Using proximity/distalness of discipline and home graduate program as our input variable does not always capture all of the characteristics of the discourse evolution and quality in the IRIFs. Specifically, some natural affinities/proximity effects exist independent of discipline/graduate program and are defined more by the nature of the research project itself. Thus, we have observed that biomedical engineers engaged in stem cell engineering and life scientists focusing on cell/molecular biology share many common interests (e.g. rt-PCR, DNA microarrays, cell culture techniques), and they often engage in lively interchanges during the IRIF discussions, even though they are ostensibly distal colleagues. These biomedical engineers may have more in common with their biologist colleagues than with their fellow biomedical engineers oriented toward biomaterials, biomechanics, and the design, fabrication, and analysis of micro and nano engineered biointerfaces. This latter subset of biomedical engineers may share more of a common language and experimental platform of techniques with colleagues doing similar research but under the auspices of materials engineering and chemistry graduate programs.

Consequently, we will use the same graphical–plus–content–based approach (the GROD) that we have developed for this study and apply it to code for and to investigate other factors/variables that might contribute to discourse development and to tackling the learning and dissemination challenges. These other attributes/input variables include the afore-mentioned “research project orientation” (e.g. biomaterials engineering vs. tissue engineering) – as well as more trainee–specific variables (e.g. different IGERT cohorts; post-baccalaureate
work experience or MS degree, undergraduate major, etc.). Such work is currently in process and will be reported subsequently.

In our future work, we also would like to compare behaviors of participants in our discourse community to a “control” group of students. We are interested in exploring whether it is necessary to distinguish the impact of our discourse community from any possible tendency of inherently good communicators to self-select for IGERT-type graduate programs instead of the traditional uni-disciplinary programs of the control group. Additionally, based on “lessons learned”, we will incorporate our findings into our on-going research on discourse communities in doctoral education in cross-disciplinary settings in science and engineering.

**SUMMARY:**

In this paper, we have described a cross-disciplinary learning community that we have designed and implemented in the context of an NSF IGERT program and that is broadly applicable to the research-centric and increasingly cross-disciplinary learning environment of doctoral graduate education in STEM fields. Exemplars of best practices of the learning community include providing a semi-structured format that invites community building and provides opportunities for regular participation in thematically coherent research-centric discussions around which the community can coalesce.

We have also developed and described a theoretical framework and an analytical methodology to study the patterns of discourse within the learning community. The methodology addresses the challenge of tracking discourse interactions in large groups and studying the contributions of a variety of attributes of the members of the community.
Research findings to date shows that the most challenging impediments to cross-disciplinary research environments are (i) the differences in language/terminology of disparate disciplines, (ii) the requirement to operate at all three levels of scaling tendency (tactical; strategic; big-picture). These challenges are best addressed when the discourse community is student-centered, but not student-exclusive, with skilled faculty facilitators who have not only broad subject matter knowledge but also pedagogical expertise to facilitate discussions and initiate integrative discourse.
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Figure 1: Cross-disciplinary/multi-disciplinary composition of the discourse community (COLTS) that participates in the IGERT Research Interchange Forums (IRIFs)
FIGURE 2: Methodology for Cross-Disciplinary Discourse Analysis
2A: Portion of a Graphical Record of Discourse (GROD), 2B: Annotation, 2C: Coding
(symbolic notation is described in text)
Figure 3: Three Examples of Patterns of Discourse in the Cross-Disciplinary Learning Community That Participates in the IGERT Research Interchange Forums
(Refer to text, Section II.C.3, for further explanation)