Exploring the Dynamic Interactions and Cognitive Characteristics of NSF Innovation Corps (I-Corps) Teams

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Abstract

In this pilot study, we used the Interaction Dynamics Notation (IDN), originally designed for use with engineering design teams, to explore the dynamic interactions of five NSF I-Corps™ teams engaged in a simple design activity. Our aim was to relate these interaction data to selected cognitive characteristics of the team members, as well as team design outcomes and individual perceptions related to the experience. The individual cognitive characteristics we assessed focused on cognitive style, as measured by the Kirton Adaption-Innovation inventory (KAI), while team outcomes included the novelty, usefulness, and feasibility of each team's design solutions, as well as their success within and beyond the NSF I-Corps™ program. Our findings show that the Interaction Dynamics Notation (IDN) can be readily extended to the study of entrepreneurial teams, with important insights gained from the combined study of interaction dynamics, individual cognitive characteristics as measured by KAI, and team outcomes. The results of this study demonstrate the feasibility and value of this approach for investigating the dynamic interactions of NSF I-Corps™ teams, as well as product-focused design teams in general.

1.0 Introduction

In 2011, the National Science Foundation established the NSF Innovation Corps (I-Corps™) program to prepare scientists and engineers to extend their efforts beyond university laboratories and to help them accelerate the economic and societal benefits of NSF-funded research projects that are ready to move toward commercialization [30, 31]. Each NSF I-Corps™ team has three primary members: an Academic Lead, an Entrepreneurial Lead, and an I-Corps™ Mentor. All three participate in I-Corps™ training, which provides real world, hands-on immersive learning about potential customers, product-market fit, and other elements of a business model [5]. To date, more than 1,000 academic teams have completed the canonical I-Corps™ curriculum delivered by the I-Corps™ nodes, with various degrees of commercialization success. Many more teams have completed abridged I-Corps™ training delivered through the I-Corps™ sites. A given team's success depends on many *external factors*, such as the entrepreneurial and investment ecosystems that impact them, as well as easy access to customers [5]; we believe that *internal (team) factors* may be equally important. In fact, the internal structure of I-Corps™ teams is shared by I-Corps™ teams across the country, so any insights gained about the influence of team composition, cognitive characteristics, and/or interaction dynamics will be broadly applicable, regardless of the external factors at play.

The success of any entrepreneurial team is highly dependent on their ability to integrate and leverage the diverse skills, experiences, and individual characteristics of their members in productive ways, and to communicate and synthesize their ideas effectively throughout the entrepreneurial life cycle of the team. Until recently, however, tracking the dynamics of these interactions was difficult to do in sufficient detail to understand exactly how ideas move through these teams and who is most likely to respond in different ways. Introduction of the Interaction Dynamics Notation (IDN) [39, 40] enables us to identify and study specific interaction behaviors within a team and to relate those behaviors to team members' cognitive characteristics and perceptions, as well as team outcomes. Until now, IDN has been applied primarily in the context of design teams [39-41]; extending its application to entrepreneurial teams is a unique contribution of our work.

While IDN enables us to analyze team interactions, it is also important to understand the individual characteristics of the entrepreneurial team members – i.e., *who* is interacting (and *with whom*). Many frameworks exist for characterizing individual differences; our choices are based on the rigor of the underlying theories and the reliability and validity of the related assessment instruments. In this paper, we will focus on our use of Kirton's Adaption-Innovation Theory [27] and the KAI® (Kirton Adaption-Innovation inventory), which measures individual cognitive style [26]. We are also exploring the use of ABAKAS, a validated measure of engineering innovativeness based on Ferguson, et al.'s model of that construct [13, 14]; that work will be presented in future publications. The individual cognitive style data provided by KAI was used in the current study to supplement the team interaction data provided by IDN to develop a richer picture of I-Corps™ team dynamics and program-related success.

Finally, the success of an entrepreneurial team will ultimately be assessed in terms of its outcomes (e.g., evidence-based business model generated, licensing deals pursued, ventures launched, funding or other resources acquired). In the specific case of I-Corps™ teams, the goal is to help university-based researchers discover markets for their ideas and technologies, with the potential to extend those efforts into business activity; one measure of progress toward this goal is the number of customer interviews completed by each I-Corps™ team. A customer interview is viewed as an experiment, testing a set of hypotheses regarding various aspects of the business that enables the development of a sound business model. Hence, this approach has been described as "hypothesis-driven entrepreneurship" [5]. Overall, the goal of I-Corps™ is to help university researchers make sound "go/no go" decisions about their technologies, rather than guaranteeing that every team starts a business. As such, one of our aims here was to investigate I-Corps™ teams' outcomes from a perspective that would aid in this kind of decision making by exploring whether team members had shared views of their team's solutions with respect to the specifications of their target problem.

We can integrate these three views (team interactions, individual characteristics, and team outcomes) via the Input-Mediator-Outcome-Input model developed by Ilgen et al. [18] and derived from McGrath [29] (see Figure 1).

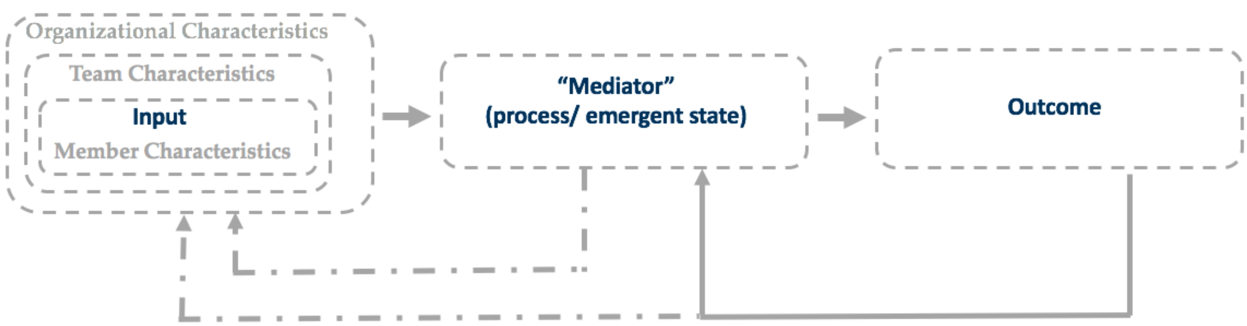


Fig. 1. Input-Mediator-Outcome-Input (IMOI) model [18, 29]

In our use of this model, individual characteristics (including demographics and cognitive style differences as measured by KAI) serve as Inputs; team interactions (as measured by IDN) serve as Mediators; and team outcomes (including team members' perceptions of their solutions) serve as Outcomes. Feedback from the assessment of team outcomes has the potential to influence both the member characteristics (e.g., learned experience) and team interactions (e.g., decision making behaviors). As described in the next section, our approaches for investigating each of these IMOI model components were originally determined through our investigation of high performance design teams; in this study, we aim to demonstrate their applicability for entrepreneurial teams in general—and NSF I-Corps™ teams in particular—as well.

2.0 Project Background

2.1 Mapping the High Performance Design Team "Genome" — and Beyond

The work presented here is an extension of an NSF-funded effort in which we are mapping the individual characteristics of design team members and their interactions to their performance in terms of innovative design to identify the behavioral building blocks of design teams that produce high performance outcomes (i.e., High Performance Design Teams). We anticipate that the identification of such behavioral building blocks will lead to scientific cognitive-behavioral models of design teams that will be applicable in academic and industry environments, as well as new tools for improving the effectiveness of those teams. In that original context, our aim is to identify and map the behavioral building blocks of High Performance Design Teams (HPDTs) through two functional objectives (see Figure 2):

1) Identify the behavioral interaction sequences and individual characteristics that characterize high performance design teams (i.e., the HPDT "genome"); and
2) Map these sequences and characteristics to innovative design outcomes.

Fig. 2. Mapping the high performance design team "genome" [41]

In discussing these original objectives with other engineering educators, we became aware of similar research questions related to entrepreneurial teams that encouraged us to explore the application of our approach to the latter. Other research questions were also raised that entrepreneurship educators felt might be answered using our approach. This led to the current project, a collaboration among engineering design educators and engineering entrepreneurship educators at Penn State University (PSU), Stanford University (SU), and the University of Wisconsin-Milwaukee (UWM), using our three-pronged approach (team interactions, individual characteristics, and team outcomes) to study NSF I-Corps™ teams.

2.2 Measuring Team Interactions: The Interaction Dynamics Notation (IDN)

Team interactions can be defined as reciprocal actions between the members of a team [39]. For both design teams and entrepreneurial teams, these include the sequences of verbal and non-verbal actions and responses between individuals as they go about understanding problems, generating solutions, making decisions, and developing prototypes. In order to measure such team interaction behavior with rigor and precision, we have chosen to use the Interaction Dynamics Notation (IDN), a visual representation system that was originally designed to capture these reciprocal actions between individuals in a design team [39, 40]; we believe these same reciprocal actions also occur in entrepreneurial teams. The Interaction Dynamics Notation is based on force dynamics theory from the field of cognitive semiotics [45], which describes the forces exerted through language. IDN represents these forces using symbols based on principles of improvisational behavior [16] (see Figure 3).

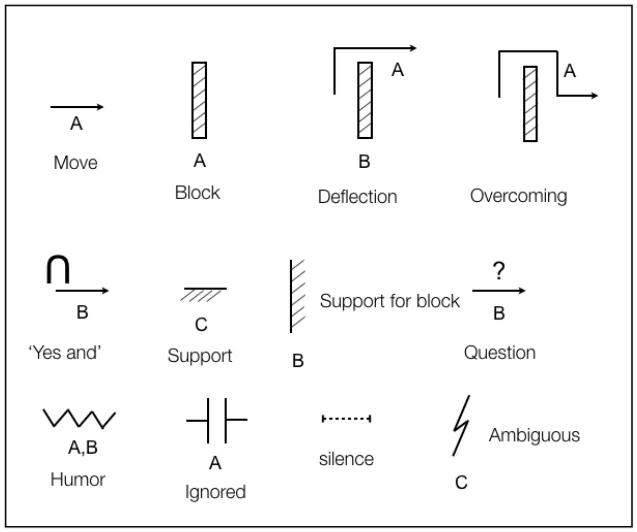


Fig. 3. Interaction Dynamics Notation (IDN) symbol set [39, 41]

Each IDN symbol is assigned to an action (both verbal and non-verbal) that is conducted by a participant and responded to by her team members. This assignment is based *not* on what the action *is*, but rather on the *response* the action receives. For example, an action will be assigned the symbol *support* because others in the team responded to that action by indicating they felt supported, not because the action "is" (was intended as) a support. Thus, IDN captures the reciprocity of *team* interaction, rather than a sequence of individual contributions. Figure 4 shows an example of a brief team interaction segment visualized and coded using IDN [39, 41], while Table 1 lists and defines the IDN symbols used in Figure 4 (plus Humor).

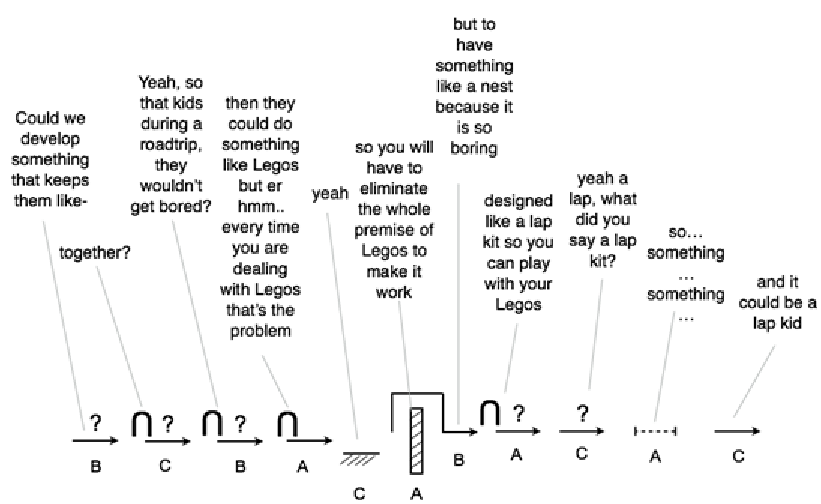


Fig. 4. Team interaction represented using IDN: A, B, C are individuals in the team [39, 41]

Table 1. Definitions of IDN symbols used in Figure 3 (plus Humor) [39, 41]

Move	**Question**	**Silence**	**Block**
A	? A		C
A 'move' indicates that a speaker has made an expression that moves the interaction forward in a given direction.	A question indicates an expression that elicits a move.	Silence is a state in the conversation when none of the participants speak as they are engaged in other individual level activities.	Block indicates an obstruction to the content of the previous move.
Support for move	**Overcoming**	**Yes and**	**Humor**
B	B C	C	A,B
Support-for-move indicates that the speaker agrees with and supports the previous move.	Overcoming a block indicates a speaker was able to overcome the block and persist on course of the original move.	A move is considered to be a 'Yes and' to the previous move if it accepts the content of the previous move and adds on to it.	Humor indicates instances of shared laughter in teams.

To apply IDN in a research setting, team interactions are first video recorded, then converted into an IDN representation, and then analyzed (see Figure 5). The video data of team interactions are initially coded into separate participant speaker turns, which also include non-verbal gestures. The data file with speaker turns is analyzed by multiple IDN analysts to create a sequence of IDN symbols; each speaker turn is assigned one symbol. This assignment is checked for inter-rater reliability using a modified Levenshtein's distance metric [51]; if the reliability is at least 0.75, the analysis continues (e.g., using data analytics software like Datameer [25]).

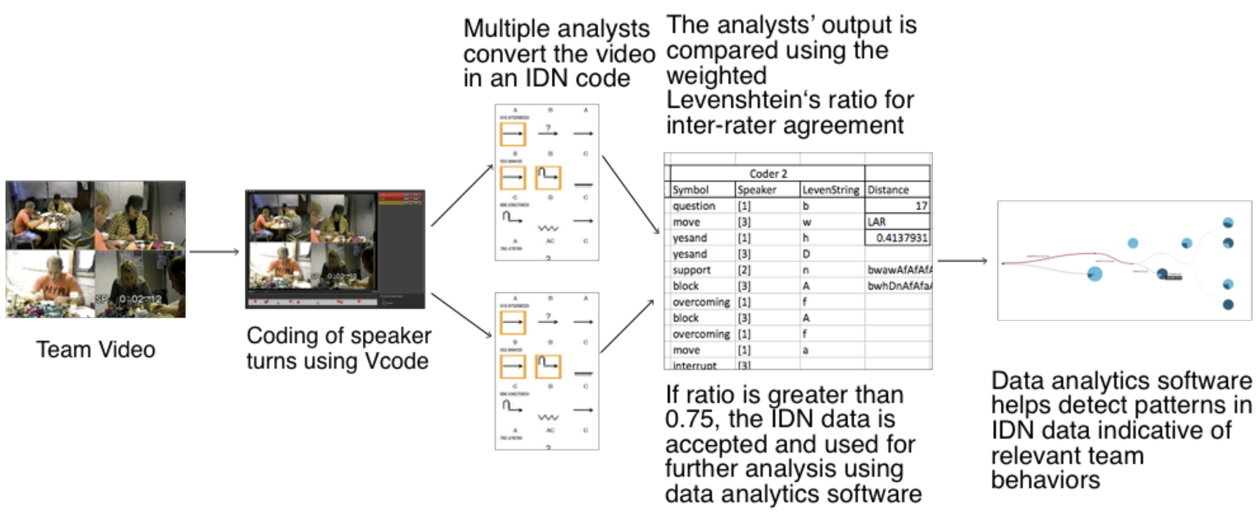


Fig. 5. Workflow for converting video data into interaction patterns using IDN [40]

2.3 Assessing Individual Characteristics: Kirton's Adaption-Innovation Theory and KAI

Among the many frameworks proposed for understanding the cognitive diversity of teams [2, 27, 42, 43], Kirton's Adaption-Innovation (A-I) theory [27] is both rigorous and highly relevant based on the problem solving context in which it was originally developed [7, 20-23, 32, 34, 37, 38, 46-49]. A-I theory is based on the key assumption that all individuals are creative, where creativity is characterized by four variables: cognitive level, cognitive style, motive, and opportunity. In this context, cognitive style and cognitive level are of greatest interest. *Cognitive level* is defined as an individual's capacity for problem solving and creative behavior, as assessed through measures of both potential capacity (e.g., intelligence, aptitude) and manifest capacity (e.g., knowledge, skills). In contrast, *cognitive style* is defined as one's stable, characteristic cognitive preference for structure in seeking and responding to change, including the solution of problems [27].

Cognitive level is unipolar (measured on a continuum from low to high), while cognitive style is a bipolar construct (measured on a continuum between two different, but equally valued, extremes). Specifically, Kirton's Adaption-Innovation (A-I) cognitive style ranges along a continuous spectrum between highly adaptive and highly innovative preferences [21, 26, 27], with mild and moderate degrees of those preferences in between. In general, individuals who are *more adaptive* prefer more structure (with more of it consensually agreed), while *more innovative* individuals prefer less structure (with less concern about consensus). Research shows that these characteristics produce distinctive patterns of behavior (working alone or with others), although an individual can and does behave in ways that are not preferred, at an extra cognitive cost (i.e., *coping behavior* [21, 27]). When individuals work in teams, their diverse cognitive characteristics will both enable and limit their collaborations. The term *cognitive gap* describes differences in cognitive level or cognitive style that can appear between two individuals, an individual and a group, two groups, or between an individual or group and the problem at hand [19, 21, 27]. In general, homogeneous teams (have smaller cognitive gaps) are less likely to experience internal conflict, but their problem solving "bandwidth" is more limited than that of heterogeneous teams (have larger cognitive gaps), who are more likely to experience greater discord.

In the context of both engineering design and entrepreneurial teams, cognitive level is typically assessed through readily available information, such as degrees earned, disciplinary domain, years' experience, known skill sets, etc. Assessment of cognitive style is best accomplished via KAI® (the Kirton Adaption-Innovation inventory) [26], which has been rigorously validated and is currently being used in a variety of contexts, including engineering, education, business, and the military [27]. For large general populations and across cultures, the distribution of KAI total scores forms a normal curve within the theoretical range of (32–160), with an observed mean of 95 (SD =17) and an observed range of (43–149); lower scores correspond to more adaptive cognitive styles, while higher scores correspond to more innovative styles.

Through multiple validation studies, Kirton also identified three sub-scores that correspond to three sub-factors of cognitive style: Sufficiency of Originality, Efficiency, and Rule/Group Conformity. These sub-factors are also normally distributed within the following theoretical ranges: SO (13–65), E (7–35), and R/G (12–60) [26, 27]. Sufficiency of Originality (SO) highlights differences between individuals in their preferred ways of generating and choosing ideas. The more adaptive tend to generate more highly detailed ideas that remain more closely connected to the original constraints of a problem, while more innovative individuals tend to generate ideas that challenge the problem definition and constraints. Efficiency (E) reflects an individual's preferred methods for managing and organizing ideas as they solve problems. The more adaptive prefer to define problems and their solutions carefully, paying closer attention to details and organization, while the more innovative often loosen or reframe the definition of a problem before they begin to resolve it. Finally, Rule/Group Conformity (R/G) reflects differences in the ways individuals manage the personal and impersonal structures in which their problem solving occurs. The more adaptive generally see standards, rules, traditions, and instructions as enabling, while the more innovative are more likely to see them as limiting. When it comes to personal structures (e.g., teams, partnerships), the more adaptive tend to devote more attention to establishing and maintaining group cohesion, while the more innovative are more likely to "disrupt" a group's internal dynamics and advocate independent action [27].

2.4 Assessing Team Outcomes

When working with engineering design teams in industry, we may evaluate the performance of each team in terms of its *solutions* (e.g., effectiveness in addressing needs, technical feasibility, originality) and its *processes* (e.g., adherence to schedule and budget, effective communication). These assessments are often highly context-specific, requiring an evaluation process that relies on appropriate experts for judgement. Nevertheless, these evaluations of team solutions and processes can also leverage well-established engineering design and project management metrics, including those described by Dean, et al. [10], Shah, et al. [36], and Anbari [3]. In working with student design teams and with the NSF I-Corps™ teams involved in this study, a different approach is required due to the academic context in which they operate. In general, we can still evaluate the solutions and processes of these teams, but the metrics will perforce be different. Solution concepts, prototypes, and detailed designs may still be evaluated using product metrics [10, 36], but in the case of entrepreneurial teams, other measures of performance will be needed (e.g., metrics related to business model assessment, number and quality of customer interviews, pivots, accuracy of inferred insights, etc.).

Qualitative assessments can also be a useful means to collect perceptions about team processes and outcomes; in this study, we piloted a team debrief document that assesses each team member's self-described emotional state over time; their perceptions of team effectiveness; interpersonal closeness; perceived novelty, feasibility, and usefulness of each team outcome; perceptions of other team members' ideas (incremental to radical); and degree of personal coping behavior. Details on the use of this debrief document will be provided in Section 3.

2.5 From Design Teams to I-Corps™ Teams

The scholarly literature is brimming with theories, models, and case studies of entrepreneurial teams in many contexts [see, e.g., 4, 11, 24, 28, 35], including 40 publications and presentations from the *ASEE Annual Conference* alone since 1996. Although a number of scholars across multiple disciplines have investigated entrepreneurial teams through the lenses of personality and/or "team dynamics" [see, e.g., 1, 6, 9, 52], these studies typically miss the Mediator element of the IMOI model by focusing their investigation on relationships between team composition (Input) and team outcomes (Output) alone; see Figure 1 for reference. This approach has the obvious weakness of ignoring the impact on team outcomes of what team members *do* when they are engaged in entrepreneurial thinking and activities, whoever they may *be*; both "who they are" and "what they do" are likely to be important, and that relative importance is not currently understood. In addition, publications devoted to I-Corps™ tend to focus at the program level [e.g., 17, 44, 50], which is not unexpected for a relatively new initiative. To our knowledge, ours is the first study to engage in a detailed analysis of the behavioral interactions of entrepreneurial teams—*in addition to* team composition (individual characteristics) and team outcomes—and the first to investigate NSF I-Corps™ teams in such depth in particular.

The extension of our investigative approach from engineering design teams (i.e., the High Performance Design Team Genome project) to entrepreneurial teams is not a long stretch, however. The methods we employ for assessing and analyzing the individual characteristics of team members (KAI), team interactions (IDN), and team outcomes (established metrics) are not restricted to the design domain, although the outcome metrics used may differ depending on the phase of the innovation process under consideration. For example, if we are studying an entrepreneurial team engaged in concept generation, then the same metrics can be used as with a design team engaged in the same phase of the process; if the entrepreneurial team is focused on business model development, however, then the outcome metrics will need to be chosen accordingly. One aim of this study is to gather evidence to support this claim, so we can expand our investigation of I-Corps™ teams to a large scale effort.

3.0 Research Methods

3.1 Research Context and Research Aims

The primary objective of the NSF I-Corps™ program is to help university-based researchers discover markets for their technologies and determine whether they are ready to move forward in starting a business based on those technologies. The NSF I-Corps™ site featured in this study, located at the University of Wisconsin-Milwaukee (UWM), brings together diverse teams from regional academic institutions to complete an abridged I-Corps™ curriculum. To date, 73 teams have completed the I-Corps™ training process at this site; these teams have achieved various levels of success in completing the process and moving beyond it in commercializing their work. Along the way, anecdotal evidence has suggested that individual characteristics, team composition, and team interactions are key factors in the success or failure of I-Corps™ teams, but until now, these hypotheses have not been investigated in detail. **Our first aim** in pursuing this line of research is to make I-Corps™ teams more effective through a better understanding of how individual cognitive characteristics and team interactions influence team outcomes, so that appropriate teaching methods can be developed to best meet the needs of each I-Corps™ team.

I-Corps™ teams at the UWM I-Corps™ site follow the national model in terms of structure [30, 31], with at least three core members in each team: an Academic Lead (AL), an Entrepreneurial Lead (EL), and a Mentor (M). The *Entrepreneurial Lead* can be a faculty member, post-doctoral scholar, student, professional staff member, or alumnus of the academic institution with relevant knowledge of the technology and a deep commitment to investigating the commercial landscape surrounding the proposed innovation. The *Academic Lead* is typically a faculty member, responsible for overall project management, who has an academic appointment that would qualify him/her to submit proposals or play the role of PI in subsequent submissions to NSF. The *Mentor* is typically an experienced or emerging entrepreneur with expertise in transitioning technologies out of academic labs; he or she is responsible for guiding the team forward and tracking progress [30, 31]. Mentors play the role of objective evaluators of the team's customer discovery progress (carried out by the EL and AL) and provide feedback to the team.

Mentors often also serve as an extension of the I-Corps™ teaching team and co-facilitate learning. For example, Mentors are expected not to direct the team towards a conclusion but rather toward evidence or methods of evidence collection (typically in the form of a customer interview). Sometimes teams identify their own I-Corps™ Mentor, but for the most part, the

UWM I-Corps™ program leads match Mentors to teams. In addition to identifying and developing teaching methods that align with the needs of each I-Corps™ team, **a second aim** of our research here is to improve the "Mentor matching process" through a better understanding of how I-Corps™ teams interact and the role that Mentors play in those interactions. For teams that provide their own Mentors and/or to accommodate situations where Mentor choices are limited, we aim to understand how to make those teams more effective with their given composition.

The I-Corps™ site curriculum requires teams to work together for an intense 4-week period, in which they are challenged to "get out of the building" and conduct at least 40 customer interviews. I-Corps™ teams meet with the UWM teaching team in six sessions to receive coaching on the process and do exercises aimed at improving their performance. The UWM I-Corps™ program leads currently employ a variety of team exercises for this purpose, which they continually adapt and improve. Thus, **a third aim** of our research is to inform the revision of these exercises—and the creation of new exercises—based on a better understanding of how I-Corps™ team composition (individual characteristics) and team interactions influence team outcomes, including the number and the quality of customer interviews.

To meet our three research aims, we adapted the teaching plan for the UWM I-Corps™ training sessions to accommodate a "Team Effectiveness" workshop led by Penn State University and Stanford University project investigators, through which we piloted this study on I-Corps™ dynamic team interactions and individual cognitive characteristics. The workshop was held in March 2017 at UWM; details pertaining to the study participants, data collection, data analysis, and key findings are provided in the following sections.

3.2 Study Participants

Five teams participated in the Team Effectiveness workshop; these teams were drawn from a cross-section of recent UWM I-Corps™ cohorts based on their availability and willingness to participate. The workshop did not focus specifically on any one team's technology; the diverse group of projects included: a fundamental materials technology with applications in Li-ion batteries (physics team); a location-based information technology solution to inform effective building design (architecture team); a nursing product to improve patient safety in intensive care settings (nursing team); a robotic consumer product (engineering team); and learning innovations to improve the engineering students' skill assessment (engineering education team). Team profiles and technologies are shown in Table 2, along with I-Corps™ program-related outcomes; note that all names have been changed to preserve anonymity.

3.3 Data Collection

Data collection occurred during the one-day workshop at UWM. The workshop began with a brief background presentation about the project and our aims in understanding high performance design and entrepreneurial teams; each participant also signed a consent form prior to further participation. At the end of the background presentation, each individual completed the KAI administered by a certified practitioner (the PSU PI). Following these introductory activities, all five teams were presented with the same real-world design challenge focused on the development of an inexpensive water pump for a developing country and given one hour to complete their work. Team deliverables included two prototypes made of simple craft materials: (1) a *Best Fit prototype* (readily seen to meet the design specifications) and (2) a *Dark Horse prototype* (a potentially riskier solution that might not be feasible), as well as a brief presentation.

We recorded each team's interactions via video cameras as they developed and presented their solutions; the KAIs were scored as they worked. Following the first design challenge, each participant completed the individual debrief document described in Section 2.4. Next, we shared recent findings about IDN and delivered a short KAI feedback session, in which each person received his/her KAI results. This presentation was followed by a second design challenge focused on addressing the social isolation experienced by some children in hospitals. Once again, two prototyped solutions (Best Fit and Dark Horse) were requested, each team's interactions and presentations were recorded, and the same debrief document was administered at the end of the experience. The workshop closed with a question and answer session, during which time we also gathered general feedback on the value and format of the workshop through a short survey.

Table 2. Study participants' demographics (Teams A through E) and team technologies

Members / Roles*	**Gender**	**Discipline / Occupation**	**Education Level**	**I-Corps™ Program Outcomes**
Team A (Architecture): Location-based IT solution to inform effective building design				
AL: Andy EL: Terry M: Bill	M F M	Architecture/Student EE/Student Architecture/Professor	PhD cand. PhD cand. PhD	31 customer interviews
Team B (Engr. Ed.): Learning innovations to improve the engineering students' skill assessment				
AL: Ivan EL: Norman M: Brad	M M M	Engineering/Professor Art & Design/Professor Business/Univ. Devel.	PhD PhD MS/MBA	National I-Corps™ program (101 customer interviews)
Team C (Physics): Fundamental materials technology with applications in Li-ion batteries				
AL: Meg EL: Cathy M: Larry EM: Mike	F F M M	Physics/Professor Physics/Professor Business/Entrepreneur Physics/Staff Scientist	PhD PhD MBA PhD	39 customer interviews National I-Corps™ program Formed company Submitted SBIR grant State biz plan competition
Team D (Engineering): Robotic consumer product				
AL: Scott EL: Pete M: Butch	M M M	Eng. Mgt./Student Marketing/Student Engineering	MS cand. MS cand. PhD	38 customer interviews
Team E (Nursing): Nursing product to improve patient safety in intensive care settings				
AL: Laura EL: Rebecca M: John	F F M	Nursing/Student Nutrition/Student Software/Entrepreneur	RN; PhD cand. BS cand.	48 customer interviews

*AL=Academic Lead; EL=Entrepreneurial Lead; M=Mentor; EM=Extra Member

3.4 Data Analysis

For this study, the video data of each team were coded by at least two IDN analysts, all of whom were trained with standardized IDN coding flowcharts to ensure data reliability. Furthermore, inter-rater reliability was evaluated using the weighted Levenshtein's distance for comparing sequential data, such as two strings of symbols [51]. The mean weighted Levenshtein's ratio for IDN coding of the current teams was 0.80, which is in the moderate agreement range. Any disagreements in coding were resolved through consensus coding sessions, which involved all analysts watching the relevant video segment together, debating the disagreement, and coming to consensus about the assignment of IDN symbols.

In general, once IDN coding is complete, many possible analyses can be carried out using the rich dataset we collect from each workshop, including some or all of the following:

1. **Interaction segment analysis**: An interaction segment consists of a chain of IDN responses, each dependent on the preceding responses in the sequence and organized around a continuous coherent topic. Once IDN representations are broken down into interaction segments, the total number of segments per team is counted and used as an indicator of topical spread in the team interaction. Furthermore, the links between different interaction segments can be analyzed using the principle of links between speaker turns [see 41]. This analysis gives us the following measures per team: total number of interaction segments; ratio of linked to unlinked segments; and level of depth of links, which indicates the maximum number of linked segments (e.g., 2, 3, 4, etc.).
2. **Ideation utterance analysis**: Ideation utterances can be used as a measure of team concept generation outcomes. In our work, we utilize the ideation utterance identification scheme developed by Edelman [see 41], which counts any verbally expressed change to a previous concept as "an idea". Further, a subcategory of "unique ideas" can be identified, such that multiple verbal expressions relating to one major change could be considered as contributing one unique idea. A category of "sub-ideas" can also be used to account for different feature-related ideas belonging to each unique idea developed by a team.
3. **IDN sequence analysis**: This analysis can reveal team-level interaction sequences associated with ideation utterances in each team. The IDN data are analyzed using a decision tree method called the Classification and Regression Trees (CART) algorithm [see 41]. Decision trees are used in data mining to create predictive models of how a target (dependent) variable could be arrived at through a combination of its input (independent) variables. We use the CART algorithm implemented in Datameer® [25] to reveal possible interaction sequences of consecutive IDN responses that predict the occurrence of ideas or unique ideas for each team.
4. **Team outcomes analysis**: Example measures of team outcomes include the usability, feasibility, and novelty of each solution (Best Fit and Dark Horse) developed by a team (workshop specific), as well as the number of customer interviews (I-Corps™ specific). These and other outcome-related metrics can be assessed by outside experts and/or by the workshop participants themselves as appropriate for the deliverables/outcomes requested. These metrics can be analyzed from a number of perspectives: agreement between team members (or between team members and an outside expert); satisfaction of desired solution specifications; and/or shifts in solution characteristics over time.

5. **Analysis of individual perceptions**: Although individual perceptions are inherently subjective and therefore limited, they are an important source of insight when analyzing teams, since the perceptions of each team member can have marked effects on their interactions with other team members. In the context of this study, the individual perceptions available for analysis include: individual emotional state as experienced across each design challenge; interpersonal closeness with other team members; relative effectiveness of each team experience; and degree of coping behavior required in working with the team.
6. **Cognitive style (KAI) analysis**: In addition to characterizing the cognitive style of each individual on the team via KAI, the cognitive style diversity of each team can be further characterized via team-level metrics such as KAI range, mean, median, and standard deviation. The cognitive gaps within a team can also be analyzed and compared with perceptions of interpersonal closeness to assess individual sensitivity to cognitive differences.
7. **Correlation analyses**: Relationships among KAI scores/sub-scores, IDN symbol counts, IDN sequences, idea measures, interaction segments, team outcome measures, and some individual perceptions can be analyzed using standard statistical methods to identify statistically significant correlations among them.

Reporting results for this full spectrum of analyses for all five I-Corps™ teams from our study in a single paper is not practical. Instead, we will focus here on detailed IDN coding results and sequence analysis for one I-Corps™ team; results for all five I-Corps™ teams will be discussed with respect to cognitive style, coping behavior, and selected team outcomes, including success from an I-Corps™ training program perspective. In choosing one team for deeper analysis, we selected Team C, as it was among the most successful in terms of its entrepreneurial performance (see Table 2). Team C was quite effective at interviewing in a difficult technical domain (physics); in addition, Team C completed both the site and national canonical I-Corps™ programs, formed a company, and submitted an SBIR grant application. Finally, the NSF I-Corps™ program is aimed at university professors, and Team C represents the "archetype" customer for this program in many respects—i.e., academics who are highly successful in their research programs, without necessarily having any background in entrepreneurship or commercialization (i.e., "academic entrepreneurs").

4.0 Key Findings

In this section, we summarize seven key findings that resulted from the analyses highlighted above. The first four findings relate to all five I-Corps™ teams that participated in our study, while the final three findings refer to one team (Team C).

Finding 1: All I-Corps™ teams showed high cognitive style diversity, with innovative means.

To our knowledge, there are no previous studies of entrepreneurial teams using KAI. Previous studies of *individual* U.S. entrepreneurs using KAI have shown that as a group, individual entrepreneurs tend to be more innovative in terms of cognitive style, with a KAI group mean of 113.6 (± 15) [8, 15, 27], which is markedly higher than the general population mean of 95 (± 17). This is as expected based on theory, as Kirton notes [27, p. 74]: "in Western business culture, becoming an entrepreneur is seen as risky and boundary-breaking behavior"—features which are likely to attract individuals with more innovative cognitive preferences (i.e., higher KAI scores). Even with this more innovative mean, however, the range of cognitive styles found among individual entrepreneurs tends to be wide (>50 points), demonstrating that entrepreneurial interest and success is not the exclusive domain of the "innovator" (from a KAI point of view). Our study is the first to examine the cognitive style diversity of *entrepreneurial teams* to determine whether and how such diversity influences their operations and outcomes.

The KAI profiles of the five I-Corps™ teams in our study are shown in Table 3. From these results, we see that even this small sample exhibited high cognitive style diversity, with a KAI total score range of 58 points (across the whole sample) and maximum internal team cognitive gaps from 25 to 57 points. Based on the validated just-noticeable-difference (JND) of 10 points for KAI [27], these internal gaps are considered large and are likely to require careful handling and significant coping behavior over time. As expected, the KAI means of all five teams are more innovative (i.e., greater than 95). The sub-scores (SO, E, and R/G) are all in line with their respective KAI total scores (based on KAI statistical norms [26, 27]), indicating that the teams' behaviors and interactions related to idea generation, methodology, and conformity to rules and group norms can also be expected to be diverse.

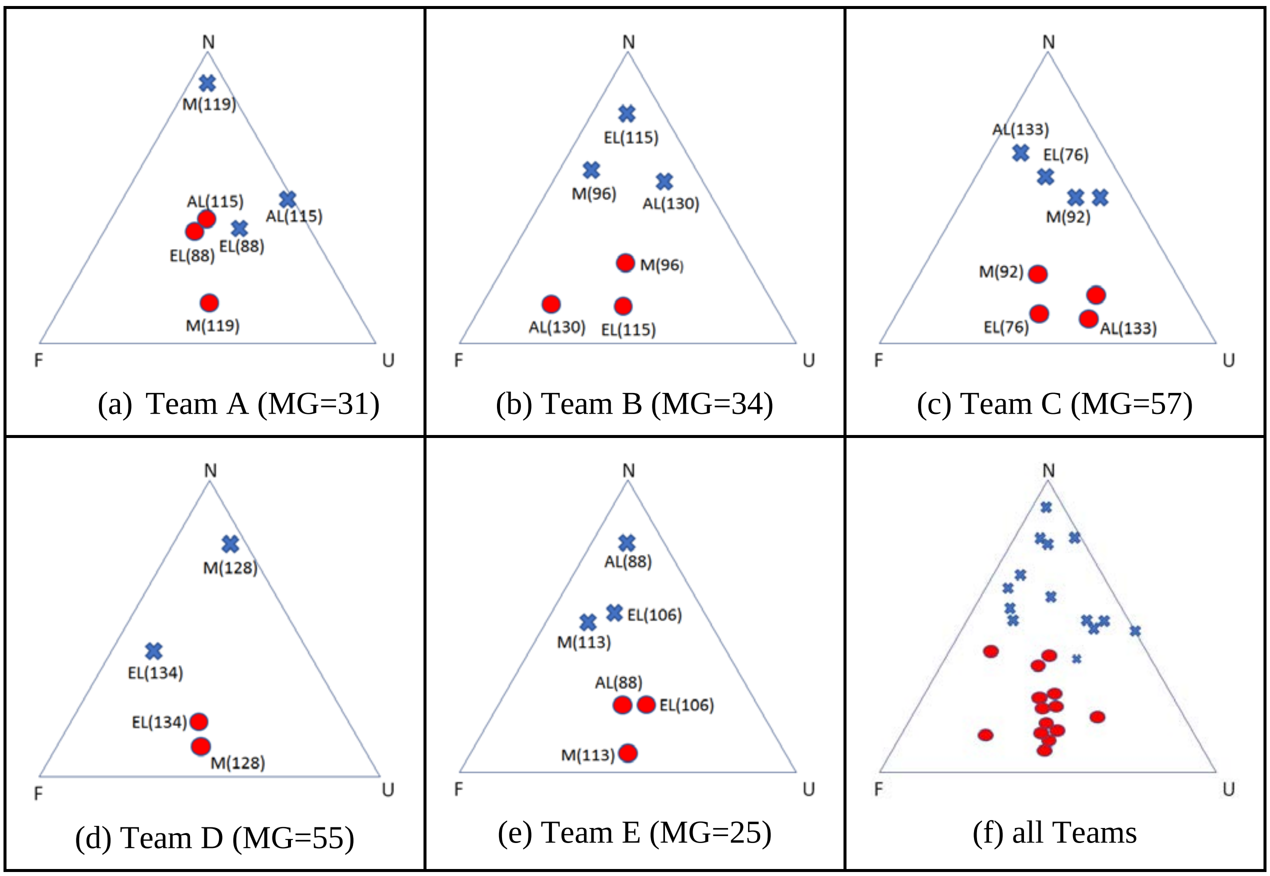
Table 3. Cognitive style (KAI) diversity of Teams A-E, with comparison of KAI mean scores (as indicators of cognitive climate) and maximum cognitive gaps

		Individual Data				***Team Data***	
Team	**Role: Person**	**KAI Total**	**SO**	**E**	**R/G**	**Max. Gap**	**Mean KAI**
A	AL: Andy EL: Terry M: Bill	115 88 119	51 41 48	21 15 28	43 32 43	31	107.3
B	AL: Ivan EL: Norman M: Brad	130 115 96	57 53 43	22 18 17	51 44 36	34	113.7
C	AL: Meg EL: Cathy M: Larry EM: Mike	133 76 92 97	57 34 37 43	21 15 15 14	55 27 40 40	57	99.5
D	AL: Scott EL: Pete M: Butch	79 134 128	34 60 49	16 23 31	29 51 48	55	113.7
E	AL: Laura EL: Rebecca M: John	88 106 113	38 50 42	15 13 24	35 43 47	25	102.3

The mean KAI score of a team serves as one measure of that team's cognitive climate—i.e., the general cognitive "flavor" of the team's approaches, behaviors, and outcomes [27]. Research shows that the just-noticeable-difference between teams is 5 points between the team KAI means [27]. With one exception (Teams B and D), the gaps between the KAI means of the I-Corps™ teams of Table 3 are all greater than 5 points, indicating that the cognitive climates of these teams should be readily distinguishable under normal operation (given sufficient time for observation). For example, we can expect Team C (the most adaptive team) to be the most structured of the five teams, while Teams B and D (with identical KAI means) will be the least structured—with Teams A and E (very close in KAI means) falling between them. Validation of these expected differences will be sought in future work via the IDN analyses of all five teams.

Finding 2: Perceptions of team outcomes were quite varied, but variations appear to be unrelated to style and I-Corps™ team role.

After each design challenge, individual team members were asked to evaluate the feasibility, novelty, and usefulness of their Best Fit and Dark Horse solutions using a triangular diagram with one metric placed at each vertex (see Figure 6). The resulting assessments for Design Challenge #1 (combined for each team) are shown in Figure 6, panels (a) through (e), where circles indicate Best Fit solutions and crosses indicate Dark Horse solutions. Each shape is labeled with the individual's I-Corps™ team role (Academic Lead, Entrepreneurial Lead, Mentor) and KAI total score. Panel (f) shows the combined assessments for all five teams for Design Challenge #1 (without labels for the sake of readability). The maximum cognitive style gap (MG) of each team is also shown in each panel.



<u>Notes</u>: F=Feasibility; U=Usefulness; N=Novelty; AL=Academic Lead; EL=Entrepreneurial Lead; M=Mentor; MG=Maximum Style Gap; Red Dot=Best Fit; Blue Cross=Dark Horse

Fig. 6. Self-assessments of solution novelty, feasibility, and usefulness (Design Challenge #1)

Visual inspection of these diagrams reveals that, in general, all team members tended to rate their Dark Horse solutions as more novel than their Best Fit solutions, which might be expected based on common perceptions about novelty [27]. Their assessments varied less between the two types of solutions in terms of feasibility and usability—i.e., the "spread" of solution assessments was narrower for both usability and feasibility. Overall, however, the spread of solution assessments was similar across all five teams, no matter how heterogeneous the team—i.e., the spread appears to be independent of maximum cognitive gap (MG). In contrast, perceptions of feasibility, usability, and novelty were all quite varied *within* each team, but these variations do not appear to be linked to cognitive style (KAI) or I-Corps™ team role (AL, EL, or M). In other words, neither the assessment of a Best Fit/Dark Horse solution in terms of feasibility, usability, or novelty, nor the differences in assessment between Best Fit and Dark Horse solutions (by an individual) are linked to the cognitive style or I-Corps™ role of that individual.

Finding 3: Coping behavior was low across all five I-Corps*™ *teams.

At the end of each design challenge, each participant was also asked to assess their general ability to "be themselves" in working with their current team during that particular design challenge, using the basic pictograms shown in Figure 7. This simple self-assessment served as a general indication of perceived coping behavior during each team task. Previous studies have shown that coping behavior generally increases with cognitive gap, as well as the duration of the collaboration [27]; this effect can be mediated by the level of respect and appreciation for diversity found in a team, as well as learned coping techniques.

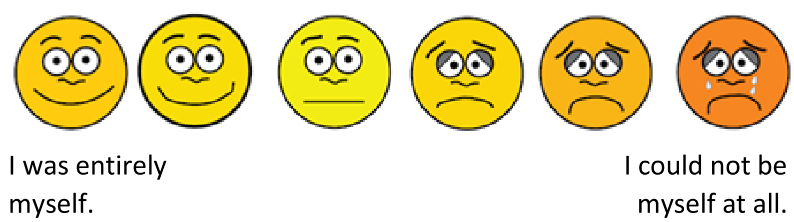


Fig. 7. Self-assessment of coping behavior (left anchor = 1; right anchor = 6)

For the five I-Corps™ teams of our study, levels of perceived coping behavior appeared to be very low for both design challenges, independent of individual cognitive style, team style mean, and maximum cognitive gap, as shown in Table 4. This is good news for these teams, since it indicates that they have found effective means of managing their wide cognitive gaps, at least in the context of relatively short, low-risk activities like this workshop. One interesting observation may be made about Team E, however, where coping levels rose for both Laura (AL) and John (M) when their teammate, Rebecca (EL), had to leave the workshop and did not participate in Design Challenge #2. Rebecca's KAI score (106) puts her between John and Laura, where she may routinely serve as a "bridger" between their different cognitive perspectives; her absence may have created a gap which Laura and John were less accustomed to managing themselves, causing their perceived coping levels to increase slightly.

Table 4. Perceived coping behavior for Design Challenges (DC) #1 and #2: all ≤ 3

		Individual & Team Data			*Perceived Coping (1=Low, 6=High)*	
Team	**Role: Person**	**KAI**	**Max. Gap**	**Mean KAI**	**DC #1**	**DC #2**
A	AL: Andy EL: Terry M: Bill	115 88 119	31	107.3	2 2 1	1 1 1
B	AL: Ivan EL: Norman M: Brad	130 115 96	34	113.7	1 2 2	2 1 1
C	AL: Meg EL: Cathy M: Larry EM: Mike	133 76 92 97	57	99.5	3 2 1 1	1 1 1 1
D	AL: Scott EL: Pete M: Butch	79 134 128	55	113.7	1 2 1	1 n/a 1
E	AL: Laura EL: Rebecca M: John	88 106 113	25	102.3	2 1 1	3 n/a 2

Finding 4: The most successful teams all contained well-positioned potential "bridgers".

From an I-Corps™ program perspective, success can be measured in terms of the number of customer interviews completed as part of the canonical training program, as well as a team's further I-Corps™ training and/or commercial activity beyond the bounds of the initial training experience. Using these metrics, three of the five teams in our study stand out, namely: Teams B, C, and E (see Table 5). Teams B and E both surpassed the target number of interviews required in their respective training (site or national); Teams B and C participated in the National I-Corps™ program; and Team C went even further commercially by forming a company, submitting an SBIR grant proposal, and participating in the Governor's business plan competition.

Table 5. Participant I-Corps team characteristics vs. program outcomes
(well-positioned potential "bridgers" shown in bold italic font)

Members / Roles*	**Gender**	**KAI (ind.)**	**Max. Gap**	**KAI Mean**	**I-Corps™ Program Outcomes**
Team A (Architecture): Location-based IT solution to inform effective building design					
AL: Andy EL: Terry M: Bill	M F M	115 88 119	31	107.3	31 customer interviews

Team B (Engr. Ed.): Learning innovations to improve the engineering design experience					
AL: Ivan EL: Norman M: Brad	M M M	130 ***115**** 96	34	113.7	National I-Corps™ program (101 customer interviews)
Team C (Physics): Fundamental materials technology with applications in Li-ion batteries					
AL: Meg EL: Cathy M: Larry EM: Mike	F F M M	133 76 ***92**** ***97****	57	99.5	39 customer interviews National I-Corps™ program Formed company Submitted SBIR grant State biz plan competition
Team D (Engineering): Robotic consumer product					
AL: Scott EL: Pete M: Butch	M M M	79 134 128	55	113.7	38 customer interviews
Team E (Nursing): Nursing product to improve patient safety in intensive care settings					
AL: Laura EL: Rebecca M: John	F F M	88 ***106**** 113	25	102.3	48 customer interviews

If we examine the cognitive profiles of these three teams, we note the presence of at least one team member (two in the case of Team C) whose cognitive style places them in the "middle" of the cognitive gap formed by the team's most adaptive and most innovative members. These individuals are highlighted in bold italic font in Table 5. Kirton's Adaption-Innovation theory tells us that *bridging*—i.e., "reaching out to people in the team and helping them to be part of it so that they may contribute" [27, p. 247]—is a social role that can be assumed by any member of any team as a means of managing and leveraging the cognitive diversity of that team. While any individual can take on this role, it is often advantageous for that person to have a "middle position" within the cognitive style distribution of the team, so the coping required to reach out to "both sides" is minimized. Although we cannot be certain that the individuals highlighted in Table 5 actually served as bridgers within their respective teams, their presence—in conjunction with the success of their teams—suggests that they may have played a critical part in helping their teams benefit from the wide cognitive diversity within them.

The following three findings derive from the IDN analysis for one team (Team C) for Design Challenge #1; as noted earlier, we chose Team C due to its high level of success within and beyond the I-Corps^{TM} program. Because we are dealing with a very small dataset, our analysis here leads us to further research questions rather than generalizable inferences; we view these questions are important findings in themselves as they impact our understanding of I-Corps^{TM} team interactions and cognitive characteristics and suggest directions for further research.

Finding 5: Individual characteristic response patterns aligned with cognitive style theory.

Adaption-Innovation Theory predicts that individuals with different cognitive styles will respond to ideas and individuals differently in a team setting, all other influences being equal. To explore this phenomenon in the context of entrepreneurial teams, we counted the number of IDN response categories (e.g., *block*, *support*, *question*, etc.) coded for each member of Team C. In particular, we evaluated each individual's percent contribution in terms of IDN categories that are especially relevant to entrepreneurial teamwork (i.e., *question*, *support*, *yesand*, *block*, *overcoming*, and *deflection* behaviors) and set these against their respective KAI scores (see Table 6). In Table 6, the members of Team C are presented from left to right in decreasing order of their KAI scores, with Meg shown leftmost (being the most innovative) and Cathy rightmost (being the most adaptive). Percent contributions greater than 25% are highlighted in bold font.

Table 6. Percent contribution of IDN responses per team member: Team C, Design Challenge #1 (contributions > 25% shown in bold font)

	% Contribution (Team C)			
IDN Response Category	**Meg (KAI = 133)**	**Mike (KAI = 97)**	**Larry (KAI = 92)**	**Cathy (KAI = 76)**
question	**47.8**	15.2	14.1	22.8
support	11.9	6.7	**30.6**	**50.7**
yesand	23.4	7.1	**32.6**	**36.9**
block	13.6	18.2	**45.5**	22.7
block-support	0.0	0.0	0.0	**100.0**
deflection	0.0	16.7	**33.3**	**50.0**
overcoming	**41.7**	25.0	16.7	16.7

Question-asking is a key activity in entrepreneurial teams, since questions elicit information about unknowns the team needs to manage. Here, we find that most (47.8%) of the *question* responses in Team C came from the most innovative person on the team (Meg), followed (at 22.8%) by the most adaptive team member (Cathy). Kirton notes that while individuals of all cognitive styles ask questions, the types of questions they ask are likely to differ [27]. In particular, adaptive team members are more likely to ask questions of clarification (seek more detail), while innovative team members are more likely to ask questions that challenge the status quo (seek tangential connections). In Team C, we see evidence of Kirton's claim about question-asking as a common response across the A-I spectrum; further research (using, e.g., transcripts of the team's interactions) will be needed to determine the nature of the questions asked by each individual.

Cathy and Larry, the two most adaptive team members, had the most *yesand* responses for Team C (36.9% and 32.6%, respectively), as well as the most *support* responses (50.7% and 30.6%, respectively), *block* responses (22.7% and 45.5%, respectively), and *deflection* responses (50.0% and 33.3%, respectively). Even for *block-support*, which is similar to *support* but for a *blocking* response, Cathy contributed 100% of all incidences. A-I theory describes adaptive individuals as more consensus seeking and more aware and desirous of agreement within a team than their more innovative peers [27], which may explain Cathy and Larry's relative dominance in terms of *yesand*, *support*, and *block-support* responses. Interestingly, Larry and Mike are close to each other on the A-I scale (cognitive gap of 5), but had very different *block* contributions (45.5% vs. 18.2%, respectively). Perhaps the majority contribution by Larry is related to his role as team Mentor and the only person with prior entrepreneurial experience; our findings here suggest that the influence of the I-Corps^{TM} Mentor on team interaction deserves further attention.

Taken together, the *deflection* and *overcoming* response contributions suggest opposing trends. *Overcoming* responses saw the greatest contribution by Meg (41.7%), the most innovative team member, followed by Mike (25%), Larry (16.7%), and Cathy (16.7%) in decreasing order of KAI scores. On the other hand, *deflection* responses saw the greatest contribution by Cathy (50%), the most adaptive team member, followed by Larry (33.3%), Mike (16.7%), and Meg (0%) in increasing order of KAI scores. This contrast may suggest that *overcoming* behavior is more likely for more innovative individuals (i.e., higher KAI scores), while *deflection* behavior is more likely for more adaptive individuals (i.e., lower KAI scores). This hypothesis will be tested with the full dataset of I-Corps^{TM} teams.

Finding 6: Different team members responded differently to the same IDN response category.

The Interaction Dynamics Notation (IDN) converts interactions into a sequence of symbols or categories. Each symbol can be considered as one state; we can then calculate the probability of one state leading to the next state, i.e., the probability of one interaction response leading to the following response. Since we assume here that a response is dependent on the previous response, we used a Markov model and Python programming to calculate the probability of one response leading to another [33]. Since Team C has four members, only probabilities greater than 25% were considered for our analysis. The probabilities were tabulated using Excel and graphed using GraphViz [12]. We evaluated these probabilities in comparison with the KAI cognitive gap between participating individuals, as shown in Table 7.

As an example (Table 7, row 1), there is a 34% probability of a *question* response from Cathy being followed by a *move* response from Mike; the cognitive style gap between Cathy and Mike is 21 points, with Cathy more adaptive than Mike. While our analysis does not suggest any firm hypotheses about the relationship between response probabilities and cognitive gap, it does give us further insights on the behavior of individual team members. For example, while in prior analysis Meg was indicated as *asking* the most questions, here we see Cathy having the greatest probability of *answering* questions raised by the rest of the team. Cathy also has the greatest probability of responding to a *block* by Larry or Mike, though the nature of her response varies. For a *block* by Larry, Cathy has a greater probability of responding by supporting it, while for a *block* by Mike, she has a greater probability of overcoming the block. While we cannot make inferences about these relationships with KAI scores, given that we are analyzing only four individuals in one team, this analysis does indicate the value of Markov modeling with a larger dataset of teams—a topic for future investigation.

Table 7. Probability of related response patterns (Person 1 to Person 2) showing the diversity of individual responses to the same IDN response category

Person 1	**Symbol 1**	**Person 2**	**Cognitive gap**	**Symbol 2**	**Probability**
Cathy	*Question*	Mike	21	*Move*	34
		Larry	16	*Move*	26
		Meg	57	*Move*	26
	Deflection	Mike	21	*Support*	33
		Meg	57	*Move*	33
		Meg	57	*Yesand*	33
	Block	Cathy	0	*Deflection*	66
				Silence	33
	Humor	Larry	16	*Humor*	33
		Meg	57	*Humor*	26
Meg	*Overcoming*	Larry	41	*Yesand*	50
	Question	Cathy	57	*Move*	55
		Larry	41	*Move*	31
	Humor	Larry	41	*Humor*	30
Larry	*Block*	Cathy	16	*Block-support*	44
	Deflection	Meg	41	*Support*	50
		Mike	5	*Move*	50
	Question	Cathy	16	*Move*	40
		Meg	41	*Move*	32
Mike	*Block*	Cathy	21	*Overcoming*	50
	Overcoming	Meg	36	*Move*	50
		Larry	5	*Support*	50
	Question	Cathy	21	*Move*	66
		Larry	5	*Move*	33

Finding 7: Varied interaction sequence patterns were associated with idea occurrence.

Generating ideas is a critical activity for any team (as is choosing the best ideas to address the current problem); if we can understand better the likely paths that lead to ideas for a particular team (or for teams in general), we may be able to design interventions to help that team be more fluent and effective in doing so under a range of circumstances. CART analysis [25, 41] enables us to determine whether there are specific sequences of consecutive IDN responses that have a greater than 50% probability of resulting in ideas being expressed for a particular team. As an example, consider a sequence of five IDN responses (*move* → *question* → *move* → *yesand* → *yesand*) that occur from time t_1 to t_5, such that the last response results in an idea expression. We assign the following sequence labels IDN-4 → IDN-3 → IDN-2 → IDN-1 → IDN to the responses in reverse order, as shown in Table 8.

Table 8. Example IDN response sequence and idea expression with sequence levels

Time	**IDN response**	**Ideation evaluation**	**IDN sequence level**
t_1	move	not idea	IDN-4
t_2	question	not idea	IDN-3
t_3	move	not idea	IDN-2
t_4	yesand	not idea	IDN-1
t_5	yesand	idea expression	IDN

Table 9 shows the results of our CART analysis for Team C for all IDN interaction sequence patterns associated with a greater than 50% probability of an idea expression. At a glance, we see that several such sequences exist, but they are not very specific, with considerable variance in terms of the symbols that appear. The most commonly occurring sequence (43 occurrences) is shown in row 3, with a 58.1% probability of resulting in an idea expression. Reading that sequence *from right to left*, the IDN responses that resulted in an idea expression could begin with any one of (*move, yesand*, *overcoming*, *deflection*, or *yesandquestion*). The preceding response could be any one of (*overcoming*, *block*, *yesand*, *humor*, or *block-support*), preceded by anything other than (*humor, support*, or *move*), preceded by any response, and finally preceded by anything but (*silence*, *block*, or *question*).

Other characteristics sequences might not have appeared as often for Team C, but they had a higher probability of resulting in ideas. For example, the sequence shown in row 2 of Table 9 occurred only 4 times, but it had a 100% probability of resulting in an idea expression. Reading the sequence from right to left, the IDN response sequence that resulted in an idea could begin with any one of (*move*, *yesand*, *overcoming*, *deflection*, *yesandquestion*). The preceding response could be anything other than (*overcoming*, *block*, *yesand*, *humor*, *block-support*), preceded by any one of (*yesandquestion, overcoming*), preceded by any response, and finally preceded by anything but *move*. Once again, this interaction pathway has a wide variance, allowing for a multitude of IDN category types at each response level. The interaction sequence for Team C that is most specific is shown in row 1 of Table 9, with a 66.7% probability of resulting in an idea expression, though it occurred only 3 times during the team interaction session. Here, the response that is immediately associated with an idea expression is actually a *question*, which could be preceded by a *support* or *yesand* response, which could (in turn) be preceded by any IDN response, which could be preceded again by *yesand*. Thus, *yesand* appears predominantly in this sequence.

Table 9. CART analysis results for Team C showing several characteristic interaction sequences (with considerable variance) for idea expression

IDN-4 (t_1)	**IDN-3** (t_2)	**IDN-2** (t_3)	**IDN-1** (t_4)	**IDN** (t_5): Resultant idea expression	**Idea target probability (%)**	**Number of occurrences**
	Yesand	Any	Support, Yesand	Question	66.7	3
NOT (move)	Any	(yesandquestion, overcoming)	NOT (Overcoming, block, yesand, humor, block-support)	(move, yesand, overcoming, deflection, yesandquestion)	100	4
NOT (silence, block, question)	Any	NOT (humor, support, move)	(Overcoming, block, yesand, humor, block-support)	(move, yesand, overcoming, deflection, yesandquestion)	58.1	43
(silence, block, question)	Any	Any	(Overcoming, block, humor, block-support)	(move, yesand, overcoming, deflection, yesandquestion)	60	5

Taken together, these results suggest that entrepreneurial teams do have characteristic interaction sequences associated with their particular form of collaborative ideation, although these sequences may be quite complex. What remains to be determined is whether the same or similar sequences exist across teams, or whether the sequences that lead most often to idea expression differ widely from team to team. Work is underway to analyze the IDN interaction responses of the remaining four I-Corps^{TM} teams from the current sample to help address these questions.

4.1 Section Summary

In summary, our pilot study yielded the following seven findings:

1. All I-Corps™ teams showed high cognitive style diversity, with innovative means.
2. Perceptions of team outcomes were varied, but variations appear to be unrelated to style and I-Corps™ team role.
3. Coping behavior was low across all five I-Corps™ teams.
4. The most successful teams all contained well-positioned potential "bridgers".
5. Individual characteristic response patterns aligned with cognitive style theory.
6. Different team members responded differently to the same IDN response category.
7. Varied interaction sequence patterns were associated with idea occurrence.

Taken together, the impacts of these findings are twofold. First, they provide uniquely deep insights into the cognitive characteristics and interaction dynamics of NSF I-Corps™ teams—

along with the impact of these characteristics and interactions on team outcomes—that embody all three components of the IMOI model [18, 29] used to frame this work. Although there remain many questions still unanswered here, at least the Mediator component is no longer a "black box", shrouded in mystery. Secondly, our results clearly demonstrate the feasibility and value of extending our three-pronged approach for studying high performance design teams (i.e., team interactions, individual characteristics, and team outcomes) to investigate the dynamic interactions of NSF I-Corps™ teams. Investigating teams in both contexts in parallel may even bring additional insights that span both the engineering design and entrepreneurial paradigms.

5.0 Implications

5.1 Implications for Engineering Educators and Students

While this pilot study focused on entrepreneurial teams, and as such, has relevance for engineering entrepreneurship courses at many institution, some of the more general findings might be applied to team-based activities in any engineering course. Our results suggest, for example, that it would be wise to include well-positioned "bridgers" in engineering teams to help mediate cognitive style gaps in the team; failing that option, Kirton notes that other team members can be trained to take on the bridging role, even if their cognitive style does not place them in an ideal position [27]. Likewise, it would behoove engineering student teams to closely observe the interaction patterns that result in idea occurrences for them, so they can trigger those sequences when they become "stuck" in their deliberations; ideally, all team members would participate in these deliberate actions. All of these suggested steps will require higher levels of mindfulness from team members, which may also help them sort out the variations in their perceptions of team outcomes that our results suggest may occur. Determining whether triggering an interaction sequence yields the same results as the sequence occurring naturally is an open research question that will require further investigation.

The NSF I-Corps™ curriculum, once available only to a small number of academic entrepreneurs, is now rapidly spreading to mainstream engineering education. Many I-Corps™ nodes and sites offer short courses, workshops, and modules within existing engineering courses that introduce students to hypothesis-driven entrepreneurship. Several authors of this paper, who also co-teach at the UWM I-Corps™ site, have introduced the business model canvas and customer discovery to senior engineering students in several courses, including engineering capstone design and an innovation and commercialization course. Although most engineering course objectives do not involve launching a new venture, intentional team formation that leads to more cognitively diverse teams can be used as a powerful tool to increase learning outcomes in any course.

5.2 Implications for the I-Corps™ Program

The most exciting implication of this research from an I-Corps™ site teaching team perspective is that, in addition to the traditional three levers we use as educators (curriculum, pedagogy, and learning environment), there may now be potential for a fourth: team composition. We currently have the luxury of selecting a team Mentor for each I-Corps™ team; prior to this research study, the criteria for Mentor selection followed the recommendations of NSF and best practices from the Lean Startup community of practice. The focus has traditionally been on the Mentor's entrepreneurial experiences, communication skills, and ability to be a coach rather than an advisor. Based on the results of this pilot study, the KAI might be used to help bridge cognitive gaps between the academic lead (AL) and the entrepreneurial lead (EL), while IDN can be used to assess the Mentor's interactions with the team and their effects on team dynamics. We can also consider new pedagogical tools that might be designed to train mentors in team interaction. Understanding cognitive diversity and the cognitive styles of I-Corps™ teams might affect other educational levers of the I-Corps™ site training as well, including how and where we teach.

6.0 Conclusions, Limitations, and Future Work

The most obvious limitations of this work are the small number of teams involved in the study, as well as the restriction of our "deep dive" IDN analysis to only one of these teams. Clearly, if we are to discover the "genome" of successful I-Corps™ teams, we need to analyze more of them. In some cases, it may be impractical to administer KAI and to apply IDN diagnostics to every team enrolled in an I-Corps™ training experience. As a result, we intend to explore the potential for other markers of team interaction dynamics or performance that are easier to observe and analyze. For example, interview logs and incremental weekly business model canvas updates offer vast amounts of data about customers, in addition to the team members logging the interviews.

Understanding internal factors that influence some teams to be better than others in the I-Corps™ program regardless of external circumstances would be a first step in designing a successful I-Corps™ team. We have observed a role for "bridgers" in I-Corps™ teams; perhaps this is a role that is well suited for an I-Corps™ Mentor. However, it will also be interesting to explore team interaction dynamics when a Mentor is highly adaptive or highly innovative and the Academic Lead or Entrepreneurial Lead has to assume the role of "bridger."

Finally, in this study, we used traditional engineering design challenges to analyze I-Corps™ team dynamics. Our future work will involve the analysis of entrepreneurial activities that are even more closely aligned with the I-Corps™ curriculum, such as synthesis of the business model canvas. Preliminary results indicate that teams alternate between knowledge and idea domains when working on the business model canvas; we have also observed interaction patterns within these activities that lie beyond the IDN framework and need special treatment. We will continue to pursue these and other residual questions and new directions as part of our future work.

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