Team performance and improvement in a science and engineering competition

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1. INTRODUCTION

Understanding how team processes underlie team performance is key for the design of organizational strategies as well as the development of new technologies for making groups smarter [Cooke and Hilton 2015]. While macroscopic insights have been gained recently on the performance of teams in science [Wuchty 2007, Fortunato et al. 2018, Wu et al 2019], we are still lacking *in situ* quantitative insights on micro-level team processes underlying performance in such a context. Here, we introduce a testbed for studying team performance and improvement at scale in science and engineering (Figure 1). Using extensive organizational and performance data across 2,000+ teams we exhibit i) shared organizational patterns across teams, ii) features associated with performance and iii) team improvement throughout re-participations in the competition. This testbed allows to recapitulate previous results from online communities [Klug and Bagrow 2018, Riedl and Woolley 2017] while giving the opportunity to gain unprecedented insights on how team structure and dynamics affects performance and improvement.

1.1 iGEM is a unique global testbed for studying team-based science and engineering

The international Genetically Engineered Machine (iGEM) Competition is a yearly team-based genetic engineering competition organized by the iGEM Foundation. Catering primarily but not exclusively to undergraduate and graduate students, it is the leading training program in synthetic biology. Since the first competition at MIT in 2004 involving 5 university teams, the competition has grown to include 353 teams across more than four dozen countries in 2019, totally 2,000+ teams over the years.

The core challenge of the competition is to design and build living "machines" from combining DNA "parts" encoding biological functions called biobricks within an organism "chassis". Rather than a prescribed goal, teams are given an open design challenge: to build a living machine to do something *useful*. Teams register for the competition yearly in March, and the official competition cycle runs yearly around May through October. The competition culminates in teams gathering in Boston to present their projects.

One core task of the competition is for teams to produce and demonstrate the functionality of a new biobrick part for the growing repository available to teams in subsequent years. Teams must also document their accomplishments in this and other elements of the competition on a collaborative public wiki, in addition to developing a presentation and poster. Over the years additional competition elements have been added to include using models and measurement standards, and engaging in safety and responsible innovation.

The competition is designed such that teams compete both against themselves and against other teams. Teams compete against themselves to be awarded medals by achieving certain feats, such as producing and characterizing the biobrick parts, and the wiki documenting their work. Teams also compete against each other for prizes, including the best project in a growing number of application areas, such as diagnostics and manufacturing. Prizes are also awarded for best in class performance in certain aspects of the competition, like the best wiki or best biobrick part. Finally, each team also competes against all teams for the grand prize awarded to the best project. These awards are documented on the competition wiki. Medals, prizes and awards are adjudicated by peer experts across academia, industry, government and civil society around the world. Although the core criteria have remained mostly consistent over the years, the judging system now involves a sophisticated rubric and voting system involving panels of ~5 judges evaluating projects on ~64 criteria.

There are a number of aspects that make iGEM a unique testbed for studying team-based science and engineering [Palmer 2020]. First, the competition simulates in several ways a controlled experimental setup. For instance, there is a regular competition cycle in which teams performing similar tasks engage in; the average age demographics of participants is largely constant and comparable, and the teams have to accomplish similar tasks to receive medals, prizes and awards every year. Second, teams are also free to organize themselves, hence there are no restrictions on team size, and teams can choose their own project application area. Finally, the competition provides a unique largely open access platform for data that is often more difficult to obtain from scientific organizations and funders. Within a given year the lab wikis, in particular, provide a glimpse into not only the outcomes but also the research and documentation process of each science and engineering project. Over the years the dynamics of innovation can also be examined, as teams build off of each other's projects both through the parts produced and the project applications pursued.

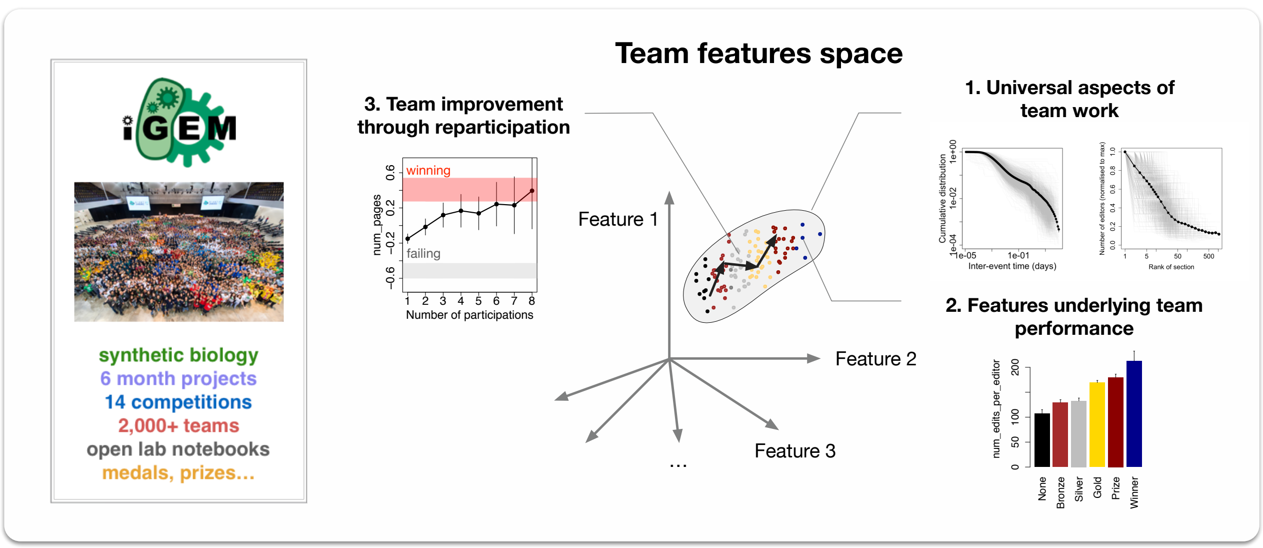

Fig. 1. Over 10 years, 2,000+ teams have participated to the iGEM competition, documenting their progress and results on open wiki websites, allowing to measure a large number of team features at scale (team size, productivity, dynamics, organization, collaboration with other teams…). We use this dataset to explore i) universal aspects of teamwork, ii) features underlying team performance in the competition and iii) team improvement throughout re-participations to the competition.

1.2 Data collection

We extracted team information at multiple levels of granularity. First, we extracted 2,569,293 wiki edits from 13,612 editors across 2,265 teams which participated in the 10 competitions between 2008 and 2018. This information was used to build internal team interaction networks consisting of bipartite networks between the wiki editors (the team students) and the wiki sections edited. Teams also collaborate with one another, and we extracted for each year the inter-team collaboration network. Teams produce BioBricks, and we extracted the number of BioBricks produced by each team and their re-use. Finally, success measures were collected, consisting of the type of medal (None, Bronze, Silver or Gold), number of special prizes, nomination as a Finalist and as a Winner of the competition.

1.3 Team performance and learning in the competition

First we explored conserved behaviors across teams. We found that teams show a bursty dynamics, as was described in online communities in [Riedl and Woolley 2017]. Their edition effort follows a deadline effect covering 5 orders of magnitudes (from minutes to 100 days), dramatically extending previous insights from conference registration data [Alfi et al 2007]. Independently of team size, teams show an inequal workload sharing (exponential distribution of contributions), comforting previous results in open-source communities [Klug and Bagrow 2016], and a nested structure of the editor-section bipartite network, indicative of a hierarchical process reminiscent of structures observed in ecological mutualistic networks [Allesina 2012]. Finally, the inter-team network structure follows a scale free degree distribution, the exponent of which is invariant across years, even under a significant inflation (x10) of the overall collaboration density, indicative that inequalities in team popularity remain unchanged even when incentivizing for inter-team collaborations.

We then observed how fluctuations around these conserved quantities of team dynamics associate with team performance. Analysis of the data showed a saturation of team productivity for teams larger than size 10. We then observed two trends for small (<10) and large teams (10+). For small teams, we observed that team size, wiki size and degree in the team collaboration network were predictive factors of performance. For both small and large teams, we found that higher burstiness, higher productivity per capita as well as prior experience in the competition were significant predictors. Finally, while team size or wiki size did not matter for large teams, intra-team network structure (nestedness and density of collaborative interactions over sections edited) were significant factors.

Lastly, teams can re-participate to the competition, with usually ~15% of team members overlapping from one year to the next. We show that teams improve their performance throughout participations, with a plateau after 2 re-participations. We show a lock-in effect for teams that started with a setback (namely, no medal the first year) and are unable to reach similar performances than other teams, similar to what was observed in the context of art careers [Fraiberger et al 2018]. We highlight potential mechanisms for the improvement and the lock-in effect: while all teams are able to improve certain features (team size, team productivity), teams with early setback are not able to increase their inter-team collaboration strength and number of instructors, indicative of contextual effects that are not measured here (isolation, lack of prestige / funding of the local host lab). Moreover, teams are generally unable to improve their team project structure, emphasizing the importance of revealing simple recommendations for organizational structure improvement that the presented work intends.

REFERENCES

Alfi,V., Parisi,G. and Pietronero,L. (2007) Conference registration: how people react to a deadline. *Nature Physics*, **3**, 746–.

Allesina, S. The more the merrier. *Nature* **487,** 175–176 (2012). https://doi.org/10.1038/487175a

Cooke NJ, Hilton ML, Eds., Enhancing the Effectiveness of Team Science (National Academies Press, 2015).

Fortunato,S., Bergstrom,C.T., Börner,K., Evans,J.A., Helbing,D., Milojević,S., Petersen,A.M., Radicchi,F., Sinatra,R., Uzzi,B., *et al.* (2018) Science of science. *Science*, **359**, eaao0185.

Fraiberger,S.P., Sinatra,R., Resch,M., Riedl,C. and Barabasi,A.-L. (2018) Quantifying reputation and success in art. *Science*, **362**, 825–829.

Klug,M. and Bagrow,J.P. (2016) Understanding the group dynamics and success of teams. *R. Soc. open sci.*, **3**, 160007.

Palmer MJ (2020), Learning to deal with dual use, Science 10.1126/science.abb1466.

Riedl,C. and Woolley,A.W. (2017) Teams vs. Crowds: A Field Test of the Relative Contribution of Incentives, Member Ability, and Emergent Collaboration to Crowd-Based Problem Solving Performance. *AMD*, **3**, 382–403.

Wu,L., Wang,D. and Evans,J.A. (2019) Large teams develop and small teams disrupt science and technology. *Nature*, **308**, 697.

Wuchty,S., Jones,B.F. and Uzzi,B. (2007) The Increasing Dominance of Teams in Production of Knowledge. *Science*, **316**, 1036.