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Board 358: Quantitative Network Analysis for Benchmarking and Improving Makerspaces

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Quantitative Network Analysis for Benchmarking and Improving Makerspaces: Project Outcomes

Abstract: Makerspaces on university campuses have seen tremendous growth and investments in recent years. Growing empirical data demonstrates the significant learning benefits to engineering students. Makerspaces are a new tool in the engineering educators' toolbox, and as such, much more needs to be done to ensure these spaces effectively grow and meet their full potential. This grant has been developing a novel network analysis technique for makerspaces, to enable the underlying makerspace network structure to be understood in terms of its connection to the successful and impactful functioning of makerspaces. The work has uncovered some basic structural building blocks of makerspace networks, known as modules, and the tools and students that make up those modules. This network-level understanding of the space enables actions such as effectively removing previously undiscovered hurdles for students who are underutilizing spaces, guiding the design of an effective makerspace from the ground up at locations with fewer resources, and creating effective events or course components that introduce students to the space in such a way that increases their chances of returning. A deep understanding of the network structure that creates a successful makerspace also provides guidance to educators on things like the impact of adding learning opportunities through workshop or curriculum integration and insight into the network-level impacts of the addition of new tools or staff. The work done over the past 3 years has worked to address the following key objectives: (1) understand the role that network analysis can play in both understanding the connection between the structure and successful functioning of a makerspace and (2) identify potential roadblocks that prevent students, especially underrepresented minority students, from feeling comfortable in and using makerspaces.

Introduction

This project applied network bipartite modeling and metrics to engineering makerspaces to understand and gain overall measures of time-based changes to and differences between the spaces. Figure 1 provides a visual overview of the illustrative data and the network analysis metrics that would be associated with it. The top two graphs make it very hard to tell if students are generally using more tools and thus learning more. Instead, using the network metrics of modularity and nestedness, a longitudinal understanding of changes in the space and its usage is dramatically improved. High modularity indicates students tend to only use specific groupings of tools while highly nested networks have been tied to higher resilience in the literature and indicate high variety of usage by some students and high student variety of some tools.

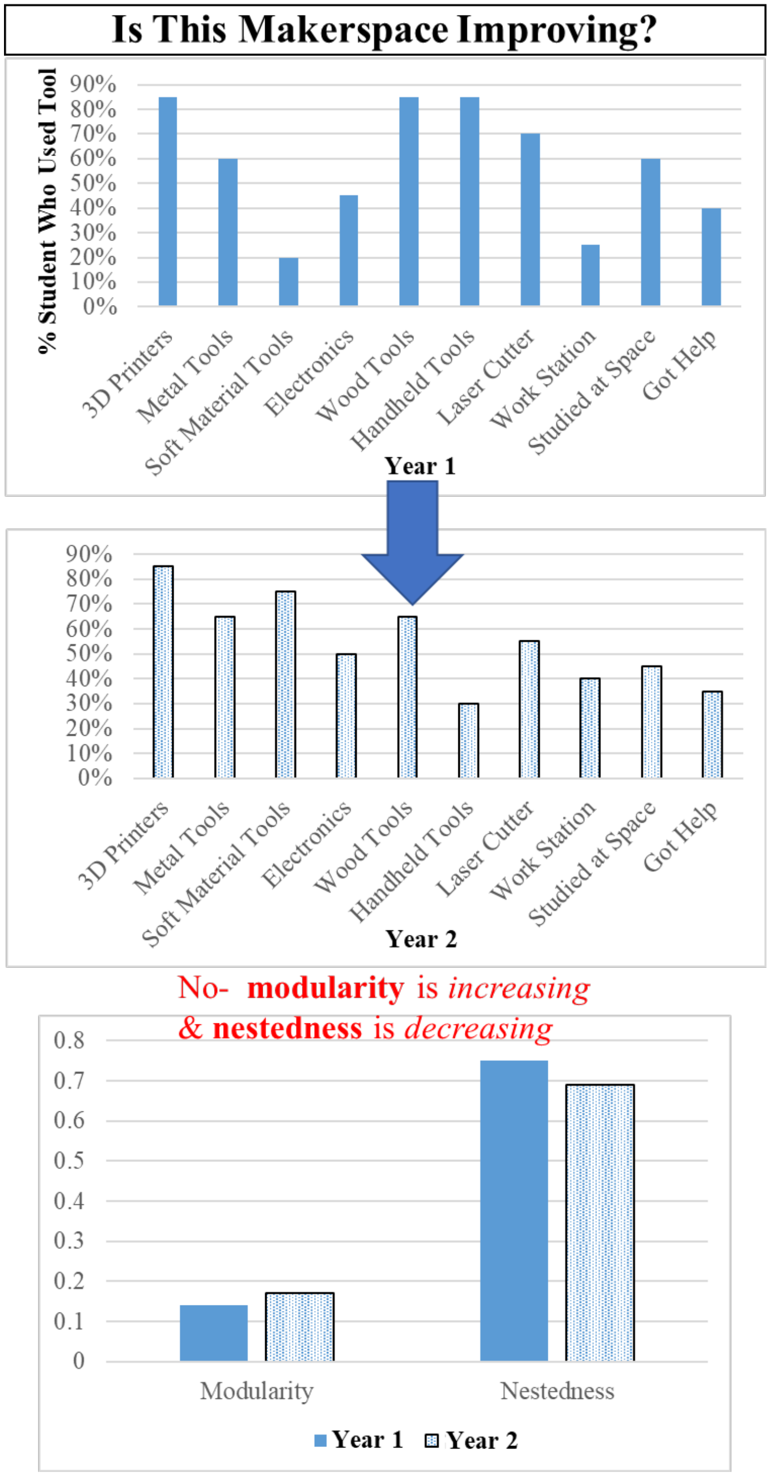

Figure 1. Often it is difficult to tell if are causing overall improvements or not (illustrative data shown here for clarity).

Data Collection

Multiple semesters of data were collected through surveys at two different universities. The online surveys asked students to identify which tools they used in the makerspace along with demographic information. Data collection included entry/exit surveys, observations to validate exit surveys, and end-of-semester surveys. The short, end-of-semester surveys were found to be highly reliable and easy to obtain for a large number of students, and most analyses were completed with this data. Data was collected at the individual tool usage level (e.g., hammers) and at the general tool group (e.g., hand tools). Since makerspaces generally do not have exactly the same tools, the spaces were compared at the tool-*group* level, and the *individual*-tool level was reserved for analyzing a single space over time. See [1-6] for more details.

Network Analysis

The network analysis starts with a directional graph representation of the makerspace as a student-tool interaction network, from there the student tool usage data is converted to a matrix of zeros and ones where if student 1 (S1) used tool 1 (T1) then entry *ij=11* is a one and zero if they did not use the tool. Generalist tools are used by a majority of students in the space and specialist tools are used by only a few. Modularity, nestedness, and connectance are network metrics that describe interaction patterns and can be calculated via the MATLAB package BiMat [7] and/or the BiMat GUI [8]. See [2, 4, 9] for more information.

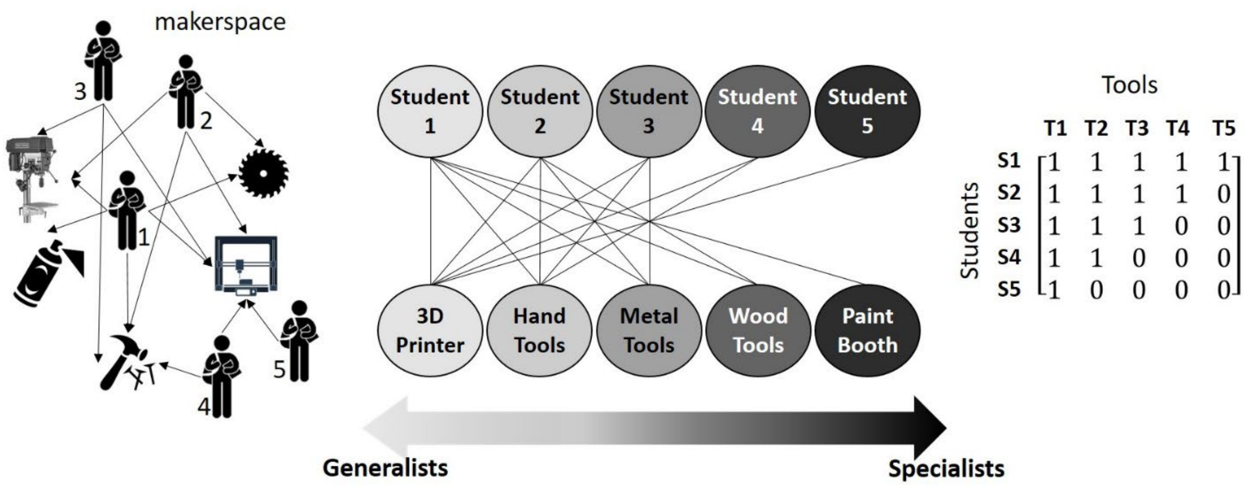

Figure 2. Overview of the network modeling and analysis process, from the (left) directional graph of the makerspace as a student-tool interaction network, to (center) the bipartite model, to the (right) bipartite interaction matrix.

Example Result

A key outcome of this project is that network analysis metrics for bipartite student-tool interaction networks of makerspaces do detect disruptions in university makerspaces. Shown in Figure 3 is students' tool usage data from the two universities over three spring semesters, including during COVID-19 and recovery afterward [1-3]. The effects of COVID-19 can be seen clearly in the tool usage data on the left. What is far less clear is if the two spaces recovered at a similar rate. The modularity and nestedness data on the right clearly show impact due to COVID-19, but also indicate that University B was able to *maintain* a high nestedness value and recovered more quickly. High nestedness generally indicates a more robust network structure more resilient to disruptions [10-12]. Due to capstone senior design, deadlines for student competitions, and other factors, fall semesters tend to have very different usage patterns than spring semester and were therefore compared separately. The data collected also demonstrate that these metrics have significant potential for use as heuristic diagnostics tools for changes in system conditions. In this case, COVID-19 was a *known* system disruption however these same metrics could be continuously monitored to indicate unexpected changes in the system. These types of indicators would then support further investigations that could then determine the cause.

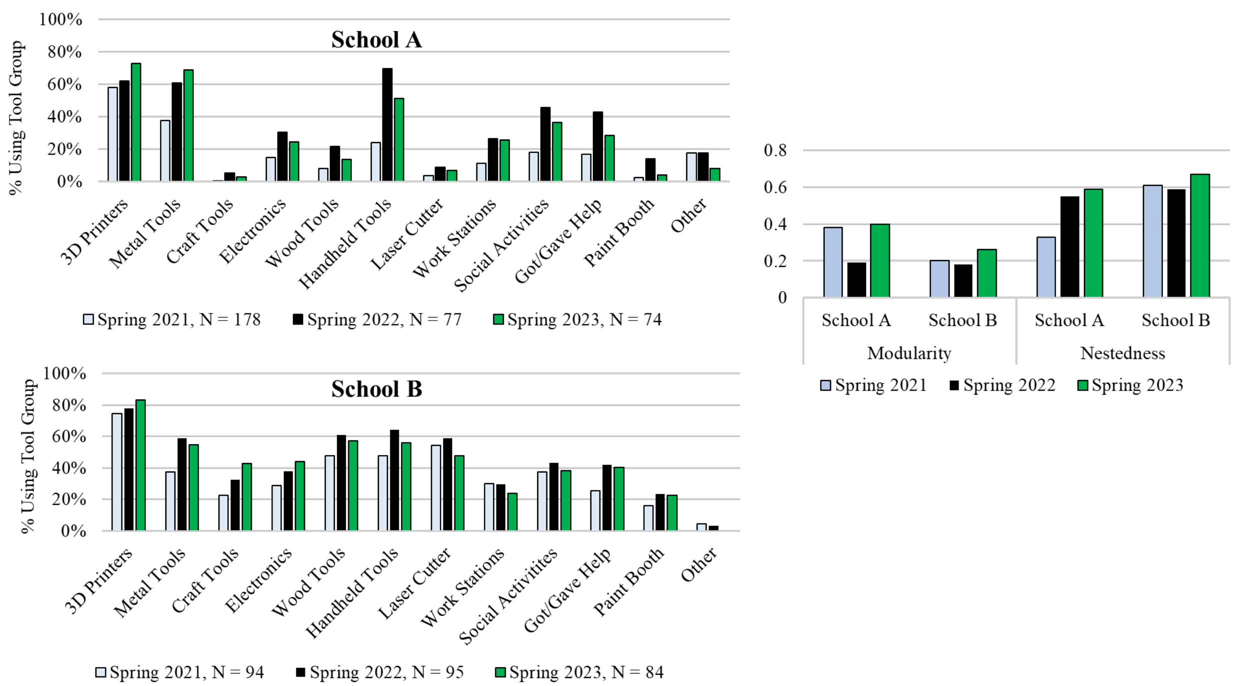

Figure 3. The percentage of students using a given tool group each semester (left) and the resulting, modularity and nestedness metrics for Schools A and B across three spring semesters (2021, 2022, and 2023) (right) [1-3]. The network metrics clearly highlight the patterns occurring in the makerspaces that are obscured in the tool group usage data. The impact of COVID-19 is clear. The nestedness of the spaces increases as COVID-19 restrictions are lifted.

Summary of Results, Conclusions, and Future Work

This paper provides just one key result from the project and summarizes other important results. The most critical results from this project include the fact that network metrics can quantitatively characterize makerspaces and clearly illustrate changes in the makerspaces studied during COVID-19, providing evidence for their role in supporting an effort that is more challenging to observe directly through tool usage data only [2, 3]. Network analysis can also identify high-impact tools that serve as critical parts of the makerspace and low-impact tools that may need more support to encourage student use [4].

COVID-19 had very significant negative impacts to the two makerspaces under study. The space that also allowed for students' self-driven projects, not just class or student competition projects, demonstrated a faster recovery, and its nestedness metrics indicated it was a more robust network. Based on the analysis of these two spaces, it is important to allow students to learn tools early and allow for personal, class, and student competition projects. Course projects often provide the initial catalysts, drawing students in over the barriers. Class usage remained present and reasonably steady throughout COVID-19. Students' personal projects likely caused School B's makerspace usage to increase faster than School A as COVID-19 restrictions were reduced [2, 3]. The analysis highlights the potential of network metrics to be used to understand how a space changes over time.

Future work should include applying the network metrics to a wider range of university makerspaces to provide further validity evidence for their usefulness. More work needs to be done on their ability to indicate barriers to participation.

Acknowledgments

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