Examining an Online Learning Environment (OLE) Feature with Dynamic Network Analysis

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ABSTRACT

Recent development in backend event logging has generated massive amount of data about learner activities in technology-enhanced learning environments. This study shows that dynamic network analysis is a powerful way to efficiently extract useful insights into learning and learning environments from such data. Taking a design-based research perspective, this study examines how 323 students and 9 teachers read each other's projects, short compositions based on comprehension of reading materials, on an online learning environment called Udio over the academic year 2014-15. It revealed interesting differences in the dynamics between students and teachers in different classrooms and raised further questions regarding how teachers' use of Udio projects could have affected the way students' interests in the same feature was sustained, which shed lights on multiple design aspects of Udio and digital learning environments in general. Arguing that teachers play an integral role in the implementation of learning technologies, this study demonstrates how the inclusion of teachers completes the picture about student learning in learning analytics. Further directions include interfacing dynamic network analysis with other types of data to achieve deeper understanding about learning and analyzing real-time data in new rounds of Udio efficacy trial.

Keywords

dynamic network, online learning environment, event log

1. INTRODUCTION

Technology evolves every day. Every few months we witness a new generation of smartphones replacing those that had just been introduced. The evolution of learning technologies operates at similar paces. Oftentimes the latest learning technologies get implemented in schools before they are thoroughly studied, while old ones become obsolete also before they can be thoroughly studied. This vicious cycle leaves schools lost in an endless pursuit of the latest technologies and pushes researchers of learning technologies to focus on the immediate benefits of technology on learning. For some learning technologies designed as scaffolding tools that make specific complex concepts more approachable, such as an iPad app that helps students understand the process of photosynthesis, this is acceptable. For more integrated learning environments designed for long-term use, however, it is imperative that we understand how learners interact with them throughout these learning environments' product lifespans. We need information such as how long it takes for the learners to become familiar with these learning environments and how long the learning activities within these learning environments can maintain the learners' interest before new ones need to be introduced.

Unfortunately, studies on the long-term effects of integrated learning environments are lacking. One of the reasons is the slow turnout of educational research data. The collection and analysis of qualitative data in the form of classroom observations and interviews takes time and resources which the short lifecycle of learning technologies do not allow. Recent development in automatic data collection techniques, such as event logging, has the potential to expedite research turnout, but useful insights can be hidden in the sheer amount of data, and we are just beginning to find methods backed by sound learning theories to extract information that can be useful for all stakeholders involved in the research of integrated learning environments, including teachers, students, researchers, technologists, and funders.

The purpose of this study is to explore whether the descriptive analysis of dynamic networks can be effective in extracting useful insights on the use of one specific feature of an integrated online learning environment (OLE) called Udio[1]. Jointly developed by the Center for Applied Special Technology (CAST[2]) and Vanderbilt University, Udio is an online literacy platform designed to improve the reading and writing skills of all learners, including English Language Learners (ELLs) and students with special needs. Providing learners with grade-level reading materials that cover a wide range of interesting topics and rich supportive measures, such as built-in dictionaries, Text-to-Speech (TTS) Engines, and various comprehension checks during and after reading, Udio is intended to be used longitudinally in middle school classrooms by teachers and students. To support the development of writing skills and sustain long-term use, Udio allows users to create "projects", short texts combining snippets of texts and images from Udio articles and writings and drawings based on users' own understanding of the texts. These projects can be shared with other Udio users from the same classroom.

This study is interested in whether and how projects were read after being created and published by Udio users. This is important because, to improve students' literacy skills, output is equally, if not more, important, as input. As will be shown later in this study, students are more likely to keep creating projects if their projects are read and their voices are heard by their peers and teachers, and to create

[1] http://udio.cast.org.
[2] http://www.cast.org.

more projects, students will be motivated to read more articles and achieve deeper understanding while reading. Thus, even though the “Read Project” function is one of the minor components of Udio, understanding how it was used over time will shed light on the overall use of Udio as a system.

There are numerous reasons why dynamic network analysis is appropriate for this study. Most importantly, while most techniques of learning analytics focus heavily on student learning, network analysis includes teachers in the picture. Since teachers decide how they would use Udio in their classrooms, their instructional decisions have great impact on the usage of Udio, and they should not be left out. Second, network graphs can be constructed, visualized, and analyzed in real time as data are collected through event logging, generating insights that are easily interpretable for all stakeholders involved in the research with various analytical backgrounds to make important decisions. Third, dynamic network analysis offers additional insights into how the network evolves, allowing researchers to see how learners interact with Udio over time and ask more specific questions when collecting and integrating other types of data to further understand what is really happening.

Additionally, these benefits are especially meaningful for this study, which takes a design-based research (DBR) perspective. DBR[3] is a research paradigm often used in the design of learning environments. Experimental-control designs, which are often dubbed as the golden standard in interventional studies, focus on studying the pre-post differences in student performances of an intervention[1]. In other words, the end results are usually the focus. DBR, on the other hand, focuses on the design process. It uses empirical data to iteratively improve the design of an intervention or a learning environment while supporting learners to achieve their learning goa. Fast turnout of research data, therefore, is especially crucial for DBR[1]. With DBR as its guideline, this study asks these research questions:

1. Was the “Read Project” function frequently used by students and teachers in Udio?
2. Did the usage of the “Read Project” function change over time?
3. Did the usage of the “Read Project” function over time vary across different classrooms?
4. How can the answers to the above questions help improve the design of Udio?

2. METHODS

2.1 Population, Sample, and Participants

The study is interested in all students and teachers who participated in the the second iteration (2014-15) of Udio’s efficacy trial, which become the population of this study. Consents were obtained from 323 students and 9 teachers from 7 middle schools on the west and east coasts of the United States (1 in New York, 1 in California, and the rest in Massachusetts), and the sample of this study includes all of these consented individuals. The goal is to achieve as large a sample size as possible, while the downside of this sampling design will be discussed in the Limitations section. Table 1 breaks down the demographics of the students in the sample. It is a fairly heterogeneous group with more male (190) than female (120) students. About 1 in 5 does not speak English as their first languages (English Language Learner, ELL status), over half are on free or reduced lunch plans, more than 50% scored “below proficient” level or the equivalent on state standardized tests, and 1/4 of the students are on Individualized Education Plans (IEP).

Table 1: Student Demographics (n=323)

	n (%)
Gender	
Female	**120 (37.1%)**
Male	**190 (58.8%)**
N/A	**13 (4.0%)**
Grade	
6	**55 (17.0%)**
7	**224 (69.3%)**
8	**42 (13.0%)**
N/A	**2 (0.6%)**
Socioeconomic Status	
Free / Reduced Lunch Plan	**211 (65.3%)**
N/A	**12 (3.7%)**
Language Status	
ELL status	**68 (21.0%)**
N/A	**11 (7.0%)**
Proficiency Level on State Tests	
Below Proficient	**182 (56.3%)**
N/A	**46 (14.2%)**
IEP Status	
IEP	**81 (25.1%)**
N/A	**13 (4.0%)**

2.2 Network Construction

Defining the nodes and edges of the network was an intuitive process. Each node in the network represents either a student or a teacher in Udio. Each edge is defined as the “Reading Project” behavior. If User A read B’s project, I define an edge pointing from A to B, with its weight being the “frequency” of such visits taking place. Defining such “frequency”, however, involved a decision between using the number of visits and using total duration of these visits, both type of information available from data. Considering that the duration of visits only records the amount of time a webpage is open, which is a poor indicator of how much time a user actually spent reading a project, I decided to define the “frequency” of visits as numbers of “valid clicks”, visits that lasted more than 20 seconds, which is more than sufficient to read most projects. Visits originating from refreshing the browser and visits to each user’s own projects (loops) were also excluded. Each edge, upon creation, stays in the network, while each further visit between the same source-target pair adds to the weight of the same edge.

To construct such a network, I used data from two major sources. One is Udio’s event log database, which stores over 600,000 user behavioral data logged between November 2014 and July 2015. The other is student demographic information, reading/writing self-efficacy and attitude survey scores, and assisted listening comprehension test scores, which are stored and managed separately. I first used Tableau as an

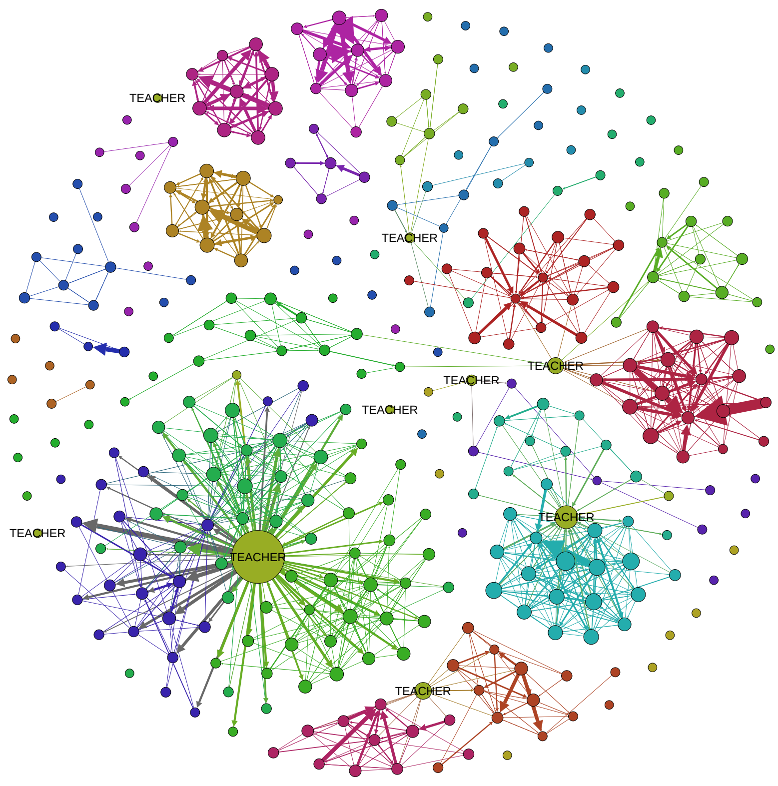

Figure 1: Visualization of Overall Network

interface between these two data sources as well as a data processor to transform and restructure the data into an incidence matrix and a list of nodes. The incidence matrix, aside from the source, target, and weight of each edge defined above, contains edge attribute information such the roles (teacher or student) of the source and the target and the timestamp of when each "effective click" occurred. The list of nodes contains select student demographic and test score information, such as their socioeconomic statuses, special education statuses, and performance on pre-post assisted reading comprehension tests.

Both datasets were then imported into R, which I used to: 1) create a gephi-compatible gexf file to construct dynamic networks and visualizations; 2) compute network statistics with the igraph and tnet package; and 3) create plots for exploratory and descriptive analyses.

3. RESULTS

3.1 Analysis of Overall Network

To answer Research Question 1: "Was the "Read Project" function frequently used by students and teachers in Udio?" I constructed the the overall network graph as of July 2015 in Figure 1. The out-degree of each node is mapped to its size (radius), while colors are mapped to the classes (called "periods" in Udio) each node belongs to[3]. Teacher nodes in the network are labeled to be distinguished from the students, and edge weights are mapped to the thickness of each edge.

Table 2: Overall Network Statistics

No. of Nodes	332 (9 teachers)
No. of Edges	1222
Total Degrees	3188
Density	0.011
Assortativity Coefficient (Gender)	-0.186
Assortativity Coefficient (ELL)	-0.21
Assortativity Coefficient (IEP)	-0.186
Assortativity Coefficient (SES)	0.035
Assortativity Coefficient (degree)	-0.159

Figure 1 and the network statistics summarized in Table 2 clearly indicate that the "Read Project" function was not very frequently used. The network is sparse with 1222 total number of edges and 3188 total out-degrees. In other words, each user in the network read other people's projects for approximately 3 times on average. The network is meant to be disconnected by research design: students from different periods could not access each others' projects; while teachers of different periods had access to different periods, the users from one school were completely isolated from their counterparts in other schools. Even so, the network density (0.011) is rather low. The distribution of out-degrees (Figure 2) also shows that most nodes in the network have out-degrees lower than 5. Figure 2 also shows the degree centrality distribution calculated with the algorithm introduced in [8]. This is a centrality measure that considers not only total out-degrees but also numbers of connections as crite-

[3]Due to missing data, teacher nodes and student nodes whose class data are missing are colored the same by Gephi. Thus teacher nodes are labeled to be distinguished form these student nodes.

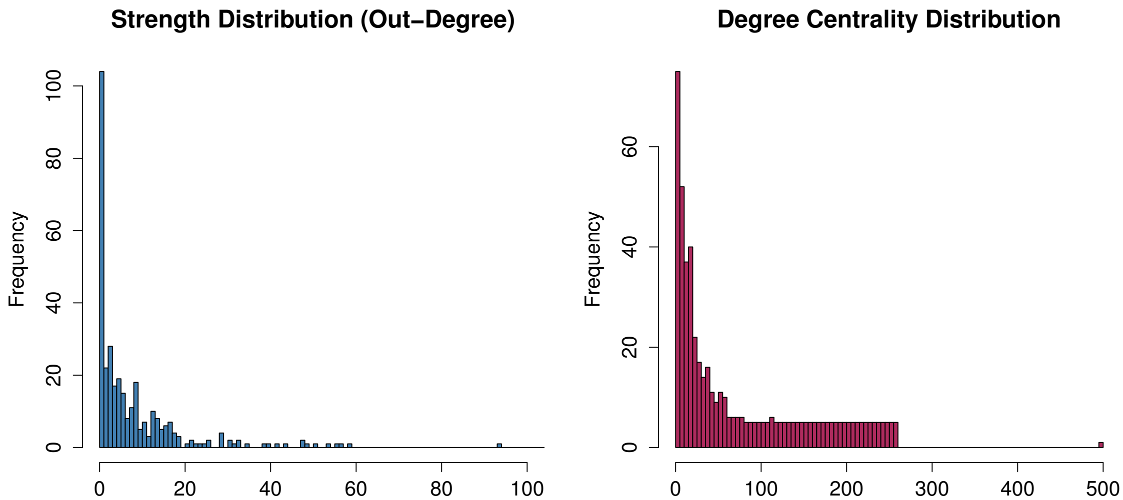

Figure 2: Out-degree Distribution vs Degree Centrality Distribution

Table 3: Teacher Degrees

Teacher ID	Teacher Total Out-Degree
10412	3
10416	464
10417	0
10420	48
10421	15
10422	4
10448	19
10471	0
10540	0

Table 4: Neighbor Information

Disconnected Nodes	62
Never Connected with a teacher	178
Connected only with a Teacher	6
Teachers never Connected	199

ria of "importance", which is more appropriate in this case of a directed weighted graph where power-based eigenvector centralitiy or alpha centrality[2] are less well-defined. Additionally, assortativity coefficients calculated from various node attributes show one characteristic of Udio: because the identities of the author are not immediately visible, students did not have a tendency to read projects of those similar to themselves.

These initial findings prompted me to seek the reasons behind the low usage. The first step was to examine how teacher activities impacted student project views. Because instructional decisions had strong control, whether teachers incorporated projects in instruction would affect students' frequency of reading projects. Table 3 clearly shows the large variation in teachers' total out-degrees. While a few teachers accessed many of their students' projects, others did not show any activity at all. I also examined the neighbors of each node shown in Table 4.

Another step was to examine whether the design of Udio's Web user interface (UI) encouraged students and teachers to access projects. I looked at the `Source` and `Elapsed Time` attributes of each edge to see how and when students and teachers accessed projects after they logged in to Udio. Figure 3 is a multi-facet histogram that shows the frequency of project visits grouped by the origin of such visits. It seems that the "Explore" page of Udio is the only place where the students (shown in red) could access other people's projects. Most students accessed projects through the list on the Explore page, where links to articles and projects co-exist. Others, though much less frequently, read projects through clicking on projects that were recommended to them, or those that were trending. These links are not visible to the students unless they click on the "Trending" and "Recommended" tabs. Thus they were much less frequently accessed, and it seems that they generally no longer got clicked 5-10 minutes after login. Curiously, there was no activity at all in the "class-recommended" group within the length of a normal Udio session. This is the where teachers' recommended readings to the students would show up for the students. Since teachers could recommend both articles and projects for the students to read, it seems that they always recommended articles over projects.

Teachers (shown in green in Figure 3), on the other hand, accessed student projects in completely different ways. The majority of their "clicks" came from the "notification" section, where they would be prompted when any student published projects. The dedicated "student projects" page, however, was almost never used.

The above analysis based on the overall network raises questions about how the design of Udio could be improved to encourage both teachers and students to read each others' projects. Here the term "design" is two-fold. First, it refers to the tangible design of Udio's Web UI. It seems that this UI could be streamlined for both teachers and students. The former would probably need a more easily accessible

Figure 3: Pageviews by Source and Elapsed Time (Seconds)

and organized space to access the projects from their students. The latter should also be given access to projects from multiple pages. For example, they should be able to access relevant projects while or after reading articles or creating their own projects. They might also enjoy reading their friends' projects if these projects are more easily identifiable and accessible. Second, teachers could benefit from more specific training and professional development (PD) sessions designed to clearly demonstrate the benefits of creating their own projects as models for the students and reading their students' projects. Although the lack of activity from some teachers does not simply imply that they were not using the "project" function, as they might prefer working with the students in person rather than through Udio, the advantages of modeling and communicating with their students through Udio should be clearly communicated to the them.

3.2 Dynamic Network Analysis

The insights from the overall network, though useful for improving the design of Udio, do not explain exactly whether and how the usage of "Read Project" function changed over the period of the efficacy study. Therefore, to answer Research Question 2, I constructed the dynamic network representation shown in Figure 4. In this case, the weights of edges increase over time as Udio users read more projects from the same person.

Figure 5 shows how total out-degrees, i.e. total number of "valid clicks" shown in purple, changed from November 2014 to July 2015. Apparently the growth of total out-degrees maintained a fairly consistent linear trend throughout this period, which corresponded well with the growth in the total number of projects created by all Udio users (orange). A vast majority of the out-degrees, or "valid clicks" were between students (blue): the corresponding edges are incident on student nodes. Teacher-to-student visits leveled out after February, and student-to-teacher visits were trivial compared with other types of visits.

Mixed information can be interpreted from Figure 5. Good news is that there seems to be consistent use of the "Read Project" function during the entire efficacy trial. Compared with most digital learning platforms whose usage decrease considerably over time, Udio seems to be able to maintain user interest. This is encouraging. However, there is more story to it. The dynamic network representation (Figure 4) shows that up until March 2015, a sizable number of the edges were yet to be established, especially between the nodes at the top of the network graph. If that is the case, and the growth of the out-degrees remained linear, does it mean that the growth of the out-degrees of the nodes that were active at the beginning of the efficacy trial slowed down, while the weights from the edges added later to the graph helped sustain the linear growth? In other words, did interest in reading projects actually decrease?

3.3 Analysis of Network Components

To answer these questions, I selected the three largest components from the overall network and compared them against each other. Each of these components is an induced subgraph, a set of one teacher and all students that are connected to the teacher or other students. Disconnected nodes were excluded, even though they might be classified as in the same "periods" as some of the nodes in the subgraphs. I call these subgraph "classes" to distinguish them from the

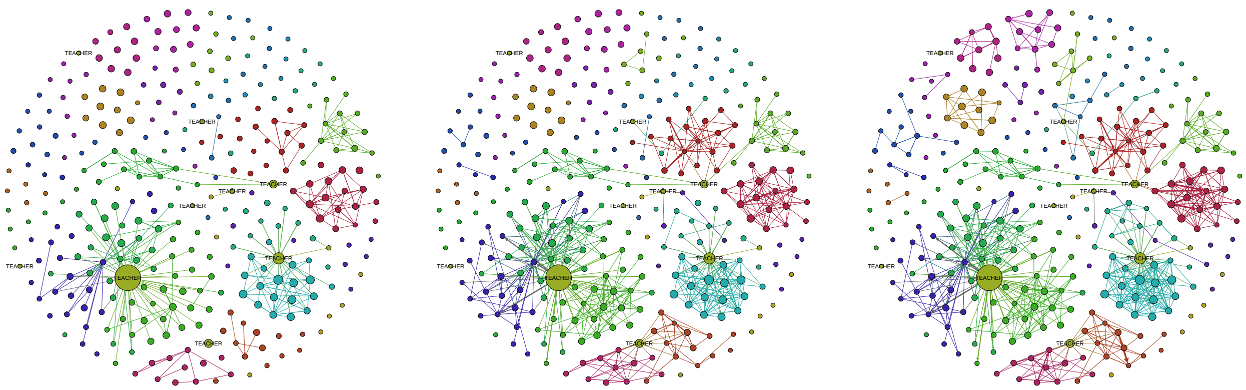

Figure 4: Visualizations of Network as of January, March, and May 2015

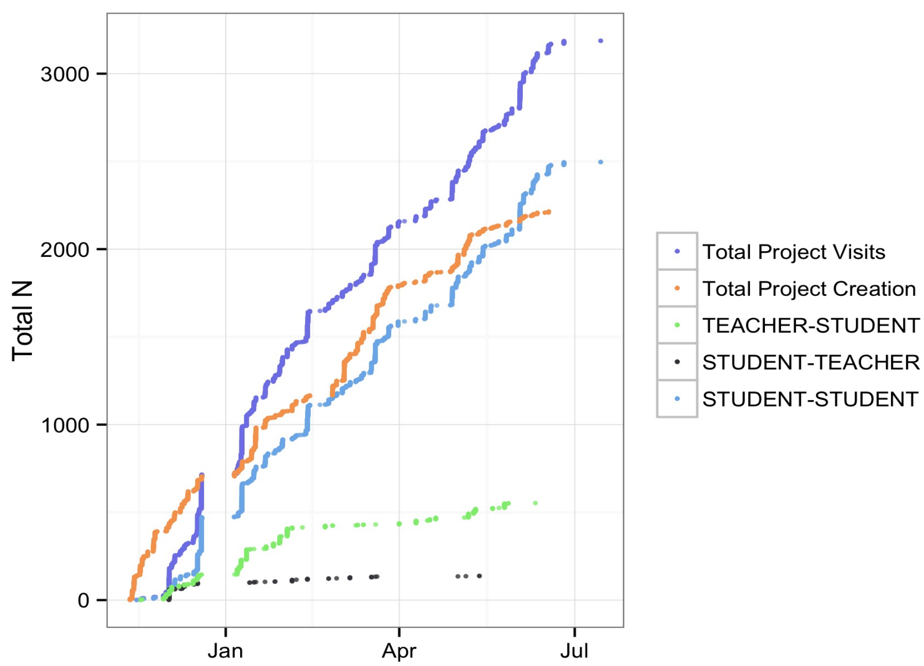

Figure 5: Total Out-degrees vs Project Creation Over Time

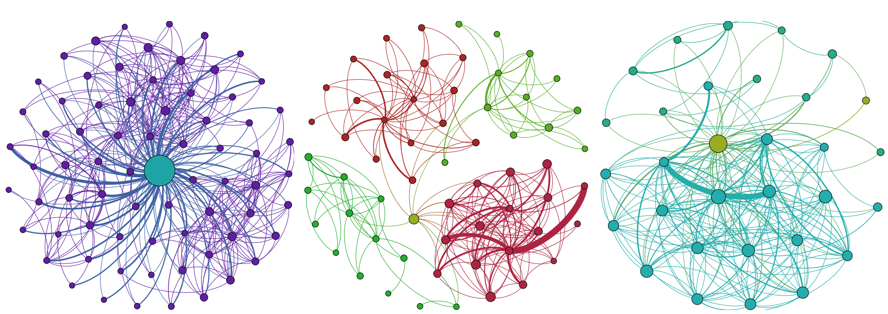

Figure 6: Visualizations of: from left to right, Class 1, Class 2, Class 3

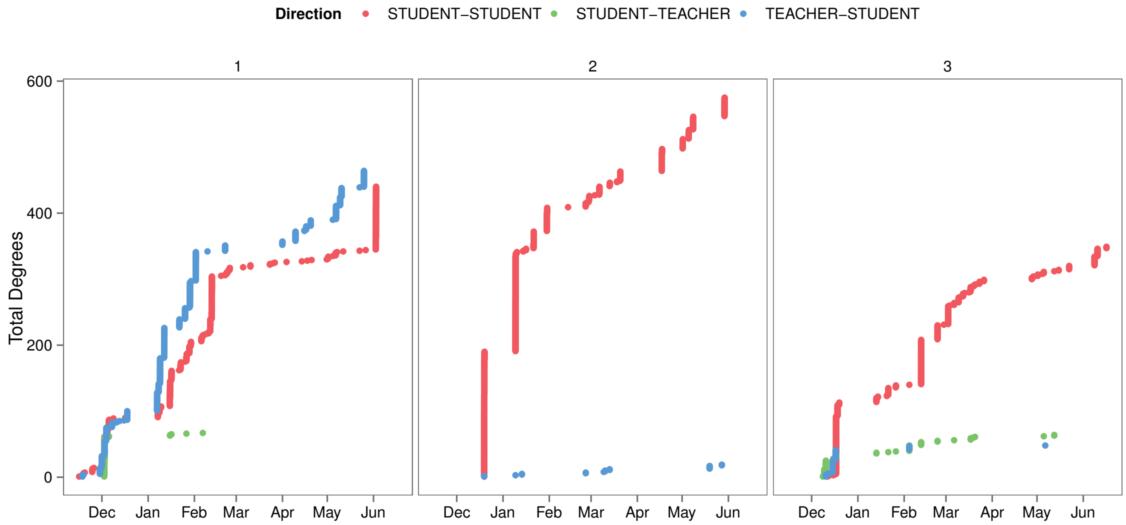

Figure 7: Out-degrees by Class

Table 5: Network Statistics of Subgraphs

	Class 1	Class 2	Class 3
N Nodes	72	61	31
N Edges	402	239	214
Teacher Out-Degree	464	19	48
Density	0.079	0.065	0.23
Transitivity	0.316	0.598	0.678
Assortativity	-0.362	-0.029	-0.319
Reciprocity	0.438	0.334	0.57

Udio "periods". For each class, I created visual representations shown in Figure 6 and computed network statistics in Table 5.

These subgraphs show differences in how the teachers were connected to the students and how the student were connected among themselves. Class 1 is a typical star-like network with the teacher playing a central role: the teacher has the highest out-degree of the overall network (464), while the student degrees are equally much lower than that of the teacher. Class 2 and 3, on the other hand, are much less teacher-centered. The force-based Futcherman-Reingold layout reveals that in both these classes, some students have higher out-degrees than others. Due to its star-like shape, Class 1 also has much lower transitivity than those of Classes 2 and 3, showing a tendency of the students to connect to the teacher rather than among themselves. While the densities of Classes 1 (0.079) and 2 (0.065) are similar, Class 3 (0.23) is much denser. Again, none of these classes demonstrates homophily: the out-degree assotativity coefficients are all negative.

Another reason why I selected these three classes is that there were activities very early on in the efficacy trial in them compared with other smaller classes, which means that I could study the dynamics of these three subgraphs over the entire period of the study. Figure 7, similar to Figure 5, shows the growth of total out-degrees over time in these three classes. It reveals intriguing similarities and differences across these classes. First, they all experienced an initial "honeymoon" period with Udio projects early in the efficacy trial, even though this period lasted longer for Classes 1 and 2 into February or even March. From the beginning of March, the growth seems to have slowed down for all classes, albeit to varying degrees. The total out-degrees for Class 2 appears to have maintained steady growth throughout the remainder of the semester. The growth of total out-degrees for Class 3, on the other hand, slowed down further towards the end of the semester. The increase for Class 1 almost stopped after March, and all of a sudden, jumped up again in June.

Although student activities exhibited relatively similar patterns in these classes, teacher activities show striking differences. In the more teacher-centered Class 1, the teacher was very diligent in reading the students' projects, with teacher out-degrees surpassing total student out-degrees from March on, whereas teacher activities in Class 2 are not evident from Figure 7. In Class 3, the teacher created and read projects at first but not as many later in the year. Meanwhile, in Class 2 and 3 where the teachers played a less central role, the growth in student-to-student connections seems to be better sustained than Class 1, where the growth took the form of discrete surges.

4. DISCUSSION

Figure 7 reveals much interesting information and raises interesting questions about teacher and student activities in these three classes. First, if we interpret the sudden surges in total out-degrees as the fact that teachers instructed students to read projects collectively, we can see that the "Read Projects" function was used in organized classroom instruction early on in the efficacy trial. After about 2-3 instructional periods, all teachers gave students more freedom to explore their classmates' projects on their own. It is encouraging to see that in Classes 2 and 3, students maintained an interest in reading their classmates' projects without being instructed to, even though such interest might not hold throughout the semester. Then the question becomes, when does the interest typically start to diminish to the extent that something needs to be done? What can be done? The answer to these questions might vary from class to class, probably depending on how the teachers demonstrate the value of projects to the students. In some classes, we might simply need to refresh the Udio library and add more content for students to create more projects. In some others, a brand new activity might be required to keep students interested in creating output.

Class 1 presents a curious case. The teacher appears to have been very enthusiastic about projects and read the students' projects throughout the year. The students, on the other hand, did not read projects too much unless instructed to. We might ask how much intervention from the teacher is optimal for the students. In Class 1, it is possible that too much control from the teacher discouraged the students from participating in a learning activity that would have otherwise been more interesting for them.

Overall, Figure 7 does substantiate the claim that the active nodes at the beginning of the efficacy trial became less active, while the new members of the network sustained the linear growth of the overall network out-degrees. The reasons behind this phenomenon, however, are probably much more complex. Apart from diminishing interest, many factors could have played a role. For example, interruptions such as the snow days, breaks, and test days could all have affected Udio usage. This is a good point of departure to connect qualitative evidence such as teacher interviews and weekly teacher logs to further investigate what happened in these classrooms.

5. LIMITATIONS

Although not discussed previously, this study could potentially suffer from biases introduced from its sampling design. Like many other similar studies, this iteration of Udio efficacy trial operated on voluntary participation, which means that the characteristics of the study sites included in this study may not represent those of all US middle schools. Then, within these study sites, about half of the students gave their permissions to be included in the study. The overall network was created using induced subgraph sampling, with each node chosen based on whether or not permission could be obtained from the student it represents. Since this is not random selection, and it is not possible to study the characteristics of those who did not grant their permission, it is difficult to determine whether the sample studied in this study is representative of the students of the participating school sites. Therefore, I treated the sample included in this study as the population while not making any generalizable claims. However, since the network is an induced subgraph of a larger one whose characteristics are unknown, any finding from this study is likely to be inaccurate and should be taken with a grain of salt. For example, a disconnected node might, in fact, have much higher out-degrees, because the student it represents read only projects from unpermissioned students.

Another limitation of this study is the definition of edge weights. I chose any view on a project that lasted more than 20 seconds as a "valid click", which carries an edge weight of 1. However, this threshold was not chosen statistically but a rather conservative estimate of how long it takes a middle schooler to read a project. The network may look considerably different with a lower threshold supported by statistics and sound theories on reading.

These two reasons might explain why no significant correlations were found between network statistics such as node out-degrees and eigenvector centralities and student psychological and test performance data. Theoretically, these measures are based on frequencies of reading other users' projects and should have some correlation with Udio users' attitudes and self-efficacy towards reading and in turn correlated with their reading outcomes. Unfortunately, my efforts in constructing regression models and structural equation models failed to achieve any model with any significance. The failure, apart from data quality issues caused by data collection, might be attributed to: 1) network statistics based on the sampling design do not paint a holistic picture of students' behaviors in Udio, 2) the "valid click" threshold is too punishing, and 3) the one teacher in the network as an outlier and the general low out-degrees of most students do not leave enough of a variance in the out-degrees and out-degree based centralities of most students.

6. CONCLUSION

Despite these limitations, the findings of this study not only answer all research questions at the beginning of the report but also raise interesting questions to be answered with further research. An immediate next step would be to examine qualitative evidence to further understand what happened in the three classes in Figure 7. Interviews of teachers and select students from each classroom, as well as weekly teacher logs are already available for analysis. Although this study focuses on the interaction between Udio users, network analysis can also be used to study the relationship between Udio users, projects, and the articles that projects are referenced on. These studies could take the form of the analyses of bipartite networks between Udio users and projects, Udio users and articles, and projects and articles.

These, however, are all done *post hoc*. The true power of dynamic network analysis on Udio event log data lies in how fast it can turn real-time data into insights that are useful to students, teachers, researchers, and developers. With another year's efficacy trial of Udio at its very beginning, I am working with Udio researchers at CAST to create real-time versions of some of the visualizations in this study based on live data. This would be especially meaningful after the study scaled up to more schools scattered around the US.

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