International Technology and Education Journal
Vol. 4 No. 1; June 2020
ISSN: 2602-2885
URL: http://itejournal.com/

Zummo, L. M. & Brown, B. A. (2020). The human limitations of flipped science instruction: exploring students learning and perceptions of flipped teaching. International technology and education journal, 4(1), 1-14.

The Human Limitations of Flipped Science Instruction: Exploring Students Learning and Perceptions of Flipped Teaching

Lynne M. Zummo, lzummo@stanford.edu, Stanford University, USA, https://orcid.org/0000-0002-1179-1675

Bryan A. Brown, brbrown@stanford.edu, Stanford University, USA, https://orcid.org/0000-0001-8350-7998

SUMMARY

Flipped instruction—the replacement of traditional in-class lecture with at-home, multimedia instruction—continues to grow in popularity. The existing evidence to support its effectiveness in K-12 science classrooms lacks substantial quantitative data to warrant such an enthusiastic embrace. The objective of this study was to clarify the relationship between flipped instruction and student learning in a high school classroom context, as well as to understand the interactions between students and technological tools that took place during flipped instruction. This quasi-experimental mixed-methods study compared learning outcomes in high school Biology students (N= 303) who experienced a flipped lesson to those of peers who experienced a control, traditional lecture-based lesson on the same topic. Average gains from pre-test to post-test were significantly higher for flipped students. Flipped students' completion of the out-of-class online learning activity was particularly important. Interview data suggest that the multimedia nature of the online activity, as well as its convenience, contributed the significant gains of flipped students.

Keywords: Flipped classrooms, flipped instruction, blended learning

INTRODUCTION

A wave of digital and multimedia based approaches have emerged to supplement traditional approaches to science teaching (Baran, 2014; Blackwell, Lauricella, Wartella, Robb, & Schomburg, 2013; Domingo & Bradley, 2018). As technology companies create learning software, teachers and teacher education programs scramble to pair best teaching practices with the ever-growing availability of new digital resources. Regardless of the form that digital resources take, they present educators a unique pedagogical dilemma. On the one hand, the obvious value of technology is impossible to ignore. The ability to access images, simulations, and video explanations of science concepts in real time presents a highly valuable resource (Gropper, 2017; Niess, 2005). However, a more cautionary approach resists the simple assumption that, because technology is new, it will improve student learning and strengthen connection to science. After all, learning is, at its core, a *human* endeavor in which learners construct understandings (Windschitl, 2002). Whether technology assists with the learning process depends on how learners interact with it—an interaction that relies on not simply the technology, but also on the human element involved (Jonassen, 1994). Thus, the influx of technology demands that educators parse apart an assumption that technology will work and the knowledge of how technology can support the human process of learning.

However, given the rapid pace of technological evolution, there rarely seems to be time to parse such a problem. A particular irony of this dilemma is rooted in the manner in which technology is incorporated into schools without thorough investigation (Foldnes, 2016). Imagine newly designed medical devices not inspected through a series of empirical tests, yet still used. Both the medical profession and the public would balk at such irresponsible implementation. However, educational innovations are often adopted without the benefit of rigorous research to fundamentally assess their impact on educational performance. Ultimately, educational technology has significant potential to enhance current science pedagogy, but the 'rush to adopt' approach may undermine the potential of incorporating such resources. One example of emergent and rapidly changing technology-based approach to science teaching is *flipped instruction*. This study examines flipped instruction in high school science classrooms.

Flipped Instruction and the Technology Adoption Dilemma

Flipped instruction involves replacing in-class instruction with recorded videos that students watch at home to prepare for class (Chen Hsieh et al., 2017; Gilboy et al., 2015). The nuances of the approach vary, but the basic assumptions are the same: students use multimedia resources to introduce themselves to the fundamentals of the science concept and arrive in class to discuss and further explore the concept (Abeysekera & Dawson, 2015; Fautch, 2015). Because students learn at home, they arrive to school with a tenuous understanding, and can thus focus on learning activities and inquiry with the teacher.

Also known as a type of *blended learning*, the flipped approach takes advantage of technological supports to introduce new concepts to students. The teacher relies on students to engage in this preparatory work at home using digital media. In many ways, this approach to teaching emerged in response to the precipitous use of

Research Article. Received: 12/19/2019 Accepted: 02/04/2020

YouTube™ and Khan Academy™ videos for learning. It is not uncommon to find videos about scientific concepts such as Hydrogen bonding with over one million views. This large volume of online video use has led educators to consider how to incorporate videos into instruction in pedagogically sound ways. Despite the zeal for incorporating these modes of instruction, the existing evidence to support the effectiveness of flipped classrooms as a pedagogical tool in science teaching is limited. Much of the initial research lacks substantial data to warrant such an enthusiastic adoption (Groves & Zemel, 2000; Straub, 2009), and is rarely conducted in K-12 classrooms.

While several studies have investigated flipped instruction, these studies are limited by two vital features. First, learning is an innately human process that requires students to actively engage in activities that promote their learning. Regardless of the quality of the technology, getting students to use the technology appropriately is a profound predictor of the value of the technological tool in science learning. Currently, most studies of the role of flipped instruction ignore a critical analysis of how students are using the technology required to make flipped instruction effective. Second, much this work has focused on undergraduate (Dantas & Kemm, 2008; Hoic-Bozic, Mornar, and Barticki, 2009; Bliuc et al, 2011) and graduate level students (Sancho, Corral, Rivas, and Gonzalez, 2006; Carbanaro et al, 2008). While there is an emerging body of literature exploring flipped instruction in K-12 settings (Abeysekera & Dawson, 2015; Chen Hsieh, Wu, & Marek, 2017; Fautch, 2015; Gilboy, Heinerichs, & Pazzaglia, 2015) and there is hope that the work can translate to K-12 STEM instruction, many questions about flipped instruction in K-12 spaces remain and conclusions are far from definitive (Lo & Hew, 2017). Yet, many continue to strongly advocate for adoption of flipped instruction in K-12 environments despite a lack of substantive data.

That said, much research highlights the *potential* of flipped instruction. Sancho et al. (2006), Chen and Jones (2007), and Carbanaro et al. (2008) all found generally positive student perceptions of flipped technology in graduate-level courses in Microbiology, Accounting, and Health Sciences, respectively. Dantas and Kemm (2008), Hoic-Bozic et al. (2009), Bliuc, Ellis, Goodyear, and Piggott (2011), and Kim et al, (2014) likewise found positive student perception of flipped technology in undergraduate courses in Physiology, Information Science, Foreign Policy, and Engineering, respectively. However, importantly, no significant differences in learning outcomes were identified in any of these cases. Of the studies that did examine students' learning outcomes, Chandra and Watters (2012) found positive impacts on learning outcomes of high school students in a flipped Physics classroom. In studies from Gilboy et al., (2015), Fautch, (2015), and Gross, Pietri, Anderson, Moyano-Camihort, & Graham, (2015) students demonstrated improved learning when engaged in flipped instruction. The collective insights of these studies suggest that flipped instruction is valuable. However, they do not address learners' interactions with the technology itself, and, thus, a critical piece of the puzzle is missing. Without understanding the ways in which learners' interactions with technology support or inhibit learning, our understanding of flipped instruction remains partial. Furthermore, whether the positive findings around flipped instruction, obtained mainly in higher education contexts, apply to K-12 classroom settings remains unknown.

The Human Subtext of Flipped Instruction

Gross, Pietri, Anderson, Moyano-Camihort, & Graham, (2015) studied biochemical science majors in an advanced Biology course. Splitting groups into flipped and non-flipped instruction conditions, the researchers found that the extent of students' pre-class use of materials significantly impacted learning outcomes. While the flipped approach to teaching was generally found to enhance students' retention, Gross et al. (2015) were able to pinpoint the amount of time spent in reviewing pre-class materials as a predictive factor in determining how a flipped approach might improve learning outcomes. Said differently, simply flipping a science classroom by using multimedia resources to begin instruction was effective *if* students spent significant time engaging with the technological resources intended to prepare them for the session. In explaining how flipped instruction impacts science students, Gross et al. wrote:

Specifically, this enhanced interaction induces better student preparation for class meetings in the flipped learning environment. More cycles of timely preparation in a flipped class likely improve in-class interactions, which position students to be more accurate in answering online homework problems. This increased accuracy extends to exams, for which grades improve substantially, particularly for lower-GPA students and female students (p. 5).

The idea that "timely preparation" was important to the effectiveness of flipped instruction further supports the claim that technology-based teaching must be explored by carefully examining the dual roles of technology and the human element of engagement with the technology in the learning process. Our study seeks to contribute to the emergent research on technology enhanced science teaching by examining both the cognitive and human dimension of technology in modern K-12 classrooms. We explored the role of flipped instruction in enhancing students' learning in high school science classrooms. Additionally, we explored the role of student behavior and engagement in predicting the effectiveness of flipped instruction.

Theoretical Framework

Explanations about why technology can improve classroom learning have been dynamic but are generally of two sorts (Alonzo & Kim, 2018; Linn, Eylon, & Davis, 2013; Mayer, 2002). One paradigm focuses on the role that the technology plays in producing cognitive understanding (Lawless & Brown, 1997; Mayer, 2002, 2003). Scholars operating from this paradigm centralize the function of technology in helping students visualize and manipulate the phenomena in ways that are impossible without technology (Mayer, 2003). The second perspective focuses on the role that technology plays as a *mediator* for learning (Choi & Hannafin, 1995; Linn, Eylon, Davis, Eylon, & Davis, 2013; Linn et al., 2014). Scholars operating from this perspective focus on how technological tools, if used appropriately, enabled students to construct understandings of phenomena as they interact with learning technology. While similar, the first perspective focuses on the technology, while the second places greater emphasis on how the student interacts with the technology to support their learning. Both perspectives laud the value of technological resources but differ in their placement of value on how students use the technology.

While we agree with many of the tenets of the first perspective, this study is rooted in a theoretical lens that aligns with the second more interactive framework. The second paradigm focuses on the intersection between cultural, historical, and distributed aspects of student cognition (Linn et al., 2013). Known in many areas of scholarship as *Activity Theory,* cultural historical approaches to distributed cognition begin with an assumption that learning happens when students are driven to learn by the situation and cultural needs of their local context (Cole, Engestrom, & Vasquez, 1997; Engeström, Miettinen, & Punamäki, 1999). This framework argues that student learning is deeply connected to the tools made available to them and the knowledge practices that are central to the learning environment (Cole & Hatano, 2010; Engeström et al., 1999). Applied to a modern learning environment, students' situations often involve limitless amounts of information via the tools of smartphones, tablets, and computers. Often, the issue is less about whether students can access the content and more about how students integrate all of the available information through local knowledge practices into a meaningful understanding of the topic they are exploring.

As an extension to constructivist perspectives on learning, an activity theory framework emphasizes the relationship between the tools that mediate learning and the cultural historical background of those involved in the learning process (Choi & Hannafin, 1995; Cole & Hatano, 2010). Figure 1 offers a representation of an activity theory approach to technology enhanced science learning that we applied to our analysis. The framework argues that student learning is deeply connected to objects made available while learning, as well as to the knowledge

practices that have been negotiated within the community (Brown et al., 1993). Applied to flipped instruction, activity theory reveals that learning is not simply a matter of instruction, but instead relies on how the learner takes on or uses specific tools available. In our case, the technology of flipped instruction—the videos and online software with which the learner interacts—constitutes the tool or tools. While previous research has explored, to some degree, outcomes and perceptions of flipped instruction, the field has examined neither students' engagement with the technologies of flipped instruction as learning tools nor construction of knowledge relative to those tools. With the lens of activity theory, it becomes important to examine this human part of the technology-enhanced learning process.

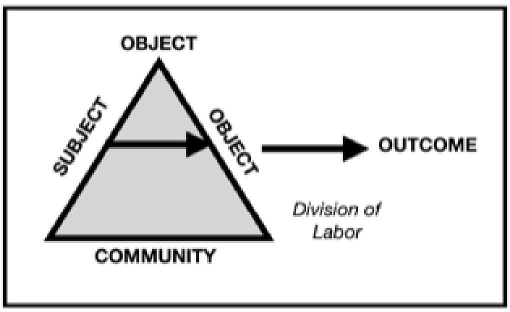

Figure 1: Activity Theory.

Within flipped instruction, to examine the interactions between the learner and the technology, one must look at students' engagement with technological resources, or tools, prior to class. A key piece of flipped instruction is that students engage in online or digital work to prepare for class. An activity theory perspective would suggest that this engagement with digital tools is situated within a community of local experts with access to distributed expertise. As students engage with digital tools at home, they can leverage the expertise of others, including others in the home community and others within an online community. These communities of local experts, including parents, friends, and online resources, allow learners to use the distributed expertise of local knowledge resources as they engage with the technological tools of flipped instruction, as studies have suggested they do (Chen & Jones, 2007). They engage with the tool not alone or individually, but rather situated within a community with expertise. Previous research approaches to flipped instruction have perhaps focused too much on individual, cognitive sense-making, whereas we assert that attention to the community in which the learners engage with technology adds an important layer to the learning process.

In addition to the situated nature of this digital learning experience, there is another critical aspect of flipped instruction that can potentially enhance students' learning. The tools associated with flipped instruction have the benefit of being quite complex and multimedia; the nature of these tools allows a multidimensional learning experience and makes such tools active components in the learning process. These tools often include video, which provides students with graphic and verbal models that support an active visualization of phenomena that otherwise may be difficult to understand (Mayer, 2009). Online, interactive assessments can enable every student to have an opportunity to explain the concepts prior to instruction (Chi, Leeuw, Chiu, & LaVancher, 1994). As students engage with such tools they are provided an opportunity to connect the with local resources that are a part of the technology enhanced science education.

Given the limited research on the topic and the prevalence of flipped instruction, scholars must question how and why a flipped approach to science teaching impacts students' learning in high school classrooms. From a theoretical perspective, activity theory helps to provide explanations for why such a practice may prove to be effective, as well as insight into the human dimension of this technology.

The Human Limitation of Technology Enhanced Science Teaching

Although, to our knowledge, previous research on flipped instruction has not made use of activity theory, some work has critiqued the technology from the angle of its human limitations, an element illuminated by activity theory. Some have suggested that flipped instruction is not effective if students do not use the technology as intended. Leer & Ivanov (2013) explained,

These technological innovations have the potential to completely disrupt the educational experience. Academics, however, must remember that technology is a tool, not a goal. Giving new knowledge to individuals, which allows them to gain specific competencies and skills while completing their personal educational goals, is the primary purpose of education. Technology can be an incredibly powerful tool in assisting students to learn in a way that suits them best, but administrators must be careful not to give greater priority to having technology than to using it effectively (Leer & Ivanov, 2013, 18)

Leer & Ivanov (2013) make an important distinction as they recognize that a potential limitation in learning science through technology is simply enacting the technology without an ear to sound pedagogy. Flipped instruction is a practice that should heed this same warning. As teachers consider using this approach, caution must be paid to recognizing how human interaction may impede the success of this approach. One fundamental limitation involves the pitfalls of a 'banking' approach to instruction (Freire, 2000) that has merely shifted to digital form. A lecture, without the benefit of dialog or pre-assessment to understand what students know, simply recreates a passive instructional environment in a digital context (Chi, 2009; Roy & Chi, 2009). Additionally, the requisite need for access to a computer or smartphone could create a digital gatekeeper along socioeconomic lines (Livingstone & Helsper, 2007). Students with jobs or intensive after school activities (e.g. athletics and arts), may be less likely to engage in the prerequisite engagement with technology that stands as the foundation for flipped instruction. Thus, the overall impact of potentially adopting a flipped approach must be filtered through an activity theory lens that assesses students' interactions with the technological tools. This study adopts a position that assumes that flipped instruction can be generative for students if they are deeply engaged in the preparatory task required before the classrooms. This study sought to examine how engaging with flipped instruction shaped learning for students in a high school science classroom.

Research Questions

To explore flipped instruction in high school science classrooms, we asked three research questions:

(1) How is use of flipped instruction related to high school students' science learning?

(2) In what ways do students interact with technological tools in flipped instruction?

(3) What are students' reflections on learning using a flipped approach to science teaching?

METHOD

This quasi-experimental study used a mixed methods approach to compare learning outcomes and student interviews from a set of classrooms that experienced flipped instruction and an equivalent set of classrooms that did not experience flipped instruction. We examined results from a pre-post test and interviewed several students (Campbell, Stanley, & Gage, 1963).

Context

We identified four Biology teachers at comparable public high schools in suburban Northern California. We met with the teachers to craft a lesson that would integrate smoothly into each teacher's existing curriculum. Together with the teachers, the research team designed two lessons on the topic of meiosis—one flipped version and one traditional. To reduce the influence of individual teaching style on the study, we asked teachers to teach two of their four sections using the traditional format and the other two sections using the flipped format (Table 1). All participating students completed pre- and post-tests to assess learning outcomes (Campbell, Stanley, & Gage, 1963).

Table 1. Teachers & conditions. Each teacher taught two flipped sections and two traditional sections, except for Teacher C, who taught only three sections of Biology.

Teacher	Session 1	Session 2	Session 3	Session 4
Teacher A	Flipped	Traditional	Flipped	Traditional
Teacher B	Traditional	Flipped	Traditional	Flipped
Teacher C	Flipped	Traditional	Flipped	--
Teacher D	Traditional	Flipped	Traditional	Flipped

We conducted interviews with a sub-sample of students from each section. We supported this data with a brief survey from students in flipped sections, although survey data was not analyzed for this paper. The quantitative assessment of students’ pre-and post-test performance provided evidence of differences in learning, while the qualitative interview data provided evidence of students’ perceptions of their experience learning using a flipped approach and insights into their interactions with the technological tools of flipped instruction.

Participants

We selected four Biology teachers from three different schools on the basis of the common demographic of students they served and a common professional training. To reduce the impact of teaching style and instructional experience, each of the teachers was selected based on their shared graduate training from the same teacher preparation program. Each teacher graduated within four years of the study, and none were first-year teachers. To maintain the fidelity of the instruction, each of the lessons was scripted with specific time allocations to reduce the overall impact of individual teacher pedagogy. Given their identical training and the similar principles and practices that underlie their pedagogical methods, these teachers maintained similar approaches to classroom teaching, which helped to reduce noise associated with selection bias. Additionally, as aforementioned, each teacher taught two sections using the flipped format and two sections using the traditional. Each teacher reported that his or her Biology sections were heterogeneous mixtures of students of comparable academic ability.

The study began with approximately n=430 participating students, but attendance issues limited the usable data to a sample of n=303. Of the participating students, approximately 70% were in 9th grade, 25% were in 10th grade, and 5% were in 11th or 12th grade. Students represented diverse ethnic backgrounds as self-reported on surveys, with approximately 35% White, 32% Mexican, 13% Chinese, 10% Latino (not Mexican), 6% Asian (not Chinese), 2% African American or Black, and 2% from other backgrounds.

Lesson Plans

As described earlier, our focus on reducing the impact of teacher performance required that we script the lessons for both the control and experimental conditions. We worked carefully to develop two lesson plans—one flipped and one traditional—that aimed to teach students key ideas about meiosis and genetics in as similar ways as possible so that the element of being flipped would be the only variable. The primary learning goal established for both lessons stated: *Students will come to understand that the process of meiotic cellular division determines how certain characteristics are shared by some siblings and not by others*. We designed both lessons using sound pedagogical practices. Oriented around the complex phenomena of siblings’ physical characteristics, the lessons included methods such as argumentation and hands-on experimentation. We adopted a situated cognition approach based on the research of Jean Lave (Brown, Collins, & Duguid, 1989). This process included establishing the problem, engaging in teacher-centered instruction (modeling), shifting towards student-centered activities (coaching), finally allowing students opportunities to explain the phenomenon as a transfer task. Both lessons centered on the question of one member of a celebrity family whose physical characteristics appear quite different from those of her siblings. Students were tasked with constructing an argument to explain the differences in her appearance. In-class learning activities included a video introduction to the problem, a hands-on experiential lab, and a writing activity. These activities were identical between the flipped classrooms and the traditional classrooms. The traditional classroom lessons also included a 10-15 minute Powerpoint-based lecture on meiosis prior to the activities, which resulted in less time for the writing activity, which was subsequently folded into that day’s homework assignment. Instead of a traditional in-class lecture, the flipped classroom lessons included a pre-class multimedia learning activity on the same topic as the lecture. Both the Powerpoint and the online assignment described the process of meiosis and used similar vocabulary. Controlling for in-class learning activities, we believe that this study offers a valid comparison of learning outcomes related to an in-class lecture and those related to an online multimedia learning activity. Table 2 shows the elements of each of the two conditions.

Table 2: A comparison of the two conditions. Because the traditional sections had less class time, given the lecture, many students did not complete the writing activity in class and continued it as post-class homework.

		Traditional	**Flipped**
Pre-Class	Pre-Test	x	x
	Online Activity		x
In-Class	Video Introduction	x	x
	Powerpoint Lecture	x	
	Lab Activity	x	x
	Writing Activity	x	x
	Post-Test	x	x
Post-Class	Writing Activity (cont'd)	x	

Flipped Out-of-Class Online Learning Activity & Tools

The flipped out-of-class learning activity involved two activities. Students were instructed to watch a specific animated video on the Internet. This 8-minute video explained the process of meiotic cell divisions by breaking down phases, depicting the crossing over process, and showing how meiosis results in haploid cells. The video featured cartoon images, music, and on-screen text combined with narration.

After watching the video, students then completed an online assignment. Questions on the assignment correlated to ideas presented in the video. Students were told that they could watch the video as many times as they wanted and/or access other digital resources as needed. Student responses to the online assignment were recorded by a survey database, which later allowed us to link pre- and post-tests with online learning activity completion.

Assessments

One to two days before the meiosis lesson, teachers administered the pre-test. Pre-tests consisted of 12 multiple-choice questions that assessed understanding of the meiotic cell division process. These items were taken from a test bank in the Holt Biology textbooks. Post-tests were similarly structured, with some repeated or rephrased questions from the pre-test. Given the fact that the teachers in the study used Holt textbook, this approach to assessment development provide a uniform platform for assessment that match the teacher's current practice. Teachers administered the post-test at the end of the lesson. Both assessments included 3-4 questions related to genetics, as the lessons strived to connect meiosis to genetic makeup.

To ensure the instruments were valid measures of students' understanding we conducted reliability assessments of the adapted Holt Biology tests. First, we reviewed all of the questions written for the validity of their written form. We then used exploratory factor analysis (EFA) to assess the variation of the student responses on the pre-test items and identified one factor with an eigenvalue of 3.61 that explained 71% of the variance. Other identified factors had very low eigenvalues and were thus not retained. Assessment items each uniquely loaded onto this factor. Reliability was assessed, and we found a Cronbach's alpha of 0.70 for all assessment items, indicating a moderately reliable assessment that appeared to assess the target construct of meiosis understanding. Based on this reliability testing, we opted to use the pre-and-post measures for determining school outcomes.

Interviews

Each teacher selected 4-6 students to represent his or her flipped sections and 4-6 students to represent traditional sections for small group interviews. Teachers reported making these selections based on convenience and, in the flipped sections, flipped learning task completion. Students who were available during our visit and who also completed the online learning task (within the flipped sections) were selected by teachers to be interviewed. Teachers believed these subsets to be reflective of their classes at large. Interviews lasted 20-30 minutes per group and included 4-6 students per group. Students from flipped sections were asked to speak about their experience as well as their typical experiences in Biology class. Students from traditional sections were asked to speak about their experience in Biology class.

Quantitative Data Analysis

Quantitative assessment data were analyzed using statistical software. In using pre-test post-test design students who are high achievers in the initial assessment are often not recognized for their improvement as they have little to gain if they score very highly on the initial assessment. To solve for this limitation, we adopted a normalized gain measure which takes into account the amount of possible improvement a student can make from pre-test to post test. Normalized gain represents the ratio of the absolute gain to the maximum possible gain (Equation 1):

$$Normalized\ Gain = \frac{Posttest\ \% - Pretest\ \%}{100 - Pretest\ \%}$$

Equation 1: Normalized gain calculation

The metric has been used to assess learning outcomes in many previous science education studies (Cheng, Thacker, Cardenas, & Crouch, 2004; Coletta, Phillips, & Steinert, 2007; Hoellwarth & Moelter, 2011). We believe that by using normalized gain, and by having each teacher teach both traditional and flipped sections, we reduced the influence of teacher impact as much as possible.

Normalized gain was calculated for each student. Students were then grouped by the type of instruction that they received—flipped or traditional. Means and standard deviations were calculated for the traditional group (regardless of teacher) and the flipped group (regardless of teacher). T-tests were performed to assess significant differences in means between the two main groups—traditional and flipped. After initial analysis, scores of flipped students were further categorized by their out-of-class online learning activity completion. We performed t-tests to assess differences in gain between those students in flipped sections who had completed the online activity and those who had not. Additional t-tests were performed to determine differences between subgroupings, such as gender. For each t-test performed, Cohen's effect size was calculated. ANOVA was used to check for differences among means of three major groups: traditional, flipped (uncompleted learning activity), and flipped (completed learning activity).

Qualitative Data Analysis

We made audio recordings of the interviews and subsequently transcribed them. After transcription, qualitative interview data were analyzed and coded for major themes. After an initial round of coding, a codebook was established and data were repeatedly checked for consistency in meeting code criteria. Three overarching ideas emerged from the data as Level 1 type codes. Most data were categorized into one of these broader codes, and then further coded into more specific Level 2 codes.

The coding involved an iterative process. First, a research team member completed an initial coding review of the qualitative data. Then, another team member reviewed the data to identify coding discrepancies. After completing that review they performed an inter-rater reliability test, which resulted in an overall reliability percentage of 95.73%. After completing a review of all codes, the team created a randomized set of approximately 30% of the total of 994 codes to review, and then reviewed each of these randomly selected codes for accuracy. The total accuracy review found that 314 of 328 randomly selected codes were accurately coded, thus yielding the 95.73% agreement rate. The analysis that follows reflects the results of the quantitative assessments of gain scores and qualitative review of students' reflections on flipped instruction.

QUANTITATIVE FINDINGS

When we reviewed the results of the pre- and post-test, we noted gains for all students. We used normalized gain to assess differences in students' learning between the flipped and traditional conditions. Table 3 provides gain measurements for students, categorized by instruction type. Students in the traditional classes demonstrated a mean gain of 0.54 (54%). By contrast, students in flipped classes showed a mean gain of 0.64 (64%). The t-test showed this difference between traditional and flipped students to be significant ($p<0.05$).

When we accounted for learning activity completion within the flipped sections, differences of greater significance emerged. Flipped students who did not engage in the final, interactive aspect of the out-of-class learning activity showed a mean gain of 0.41 (41%), which represented a significantly lower ($p<0.05$) mean gain than that of traditional students of 0.54 (54%) [Table 3b]. However, flipped students who completed the final online activity showed a mean gain of 0.71 (71%). This result represented a significantly higher gain than that of traditional students, with a p-value < 0.001 and a moderate Cohen's effect size (d) of 0.52. Flipped students who completed the online activity also showed significantly higher gains than flipped students who did not complete the activity (Figure 2) [$p<0.0001$; $d=0.97$]. Thus, student gains were significantly higher for the students who experienced flipped instruction, but only if those students completed all of the provided online learning activities. When students assigned to flipped sections did not complete all learning activities the pattern was reversed; their gains were significantly lower than those of traditional students.

Table 3a. Normalized Gain by Instruction Type

	Traditional	**Flipped**
n	**144**	**159**
Mean	**0.54**	**0.64***

Stdev	0.37	0.33
d	--	0.26

Students within the flipped condition showed significantly higher normalized gains.

* = p< 0.05, ** = p<0.01, *** = p<0.001

Table 3b. Normalized gain within Flipped Condition

	Incomplete Activity	**Complete Activity**
n	**43**	**116**
Mean	**0.41***	**0.71*****
Stdev	0.34	0.29
d	0.37	0.52

Levels of significance and Cohen's d reflect t-tests done between each group and the traditional condition. Students within the flipped condition who completed all online learning activities showed significantly higher gains than those in the traditional condition. Students within the flipped condition who did not engage with all learning activities showed significantly lower gains than those in the traditional condition.

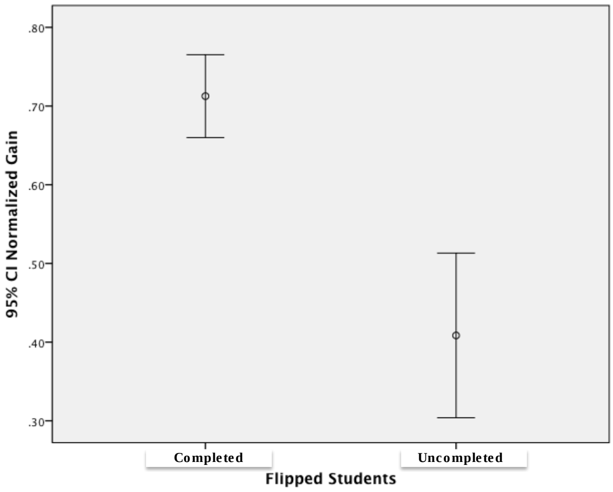

Figure 2: Comparison of normalized gain between students in flipped condition by activity completion.

Gender

We noted relationships between gender, instruction type, and gain. For girls, the mean gain was 0.56 (56%) for traditional students and 0.69 (69%) for flipped students, which represents a significant difference (p<0.05; d=0.39). For boys, there were no significant differences between traditional and flipped students.

In comparing girls' performance to boys' performance by classroom type, girls showed significantly higher (p<0.05) gains within the flipped sections. However, the effect size of 0.34 shows a relatively small influence. No significant differences between girls and boys students were found within traditional classrooms.

When we accounted for all learning activity completion by flipped students, we noted a change in the significance levels (Table 4). Girls in flipped sections who completed all aspects of the online activity showed a mean gain of 0.73 (73%). This result represented a significantly higher gain than that of girls in traditional sections who demonstrated a mean gain of 0.56 (56%; p< 000.1; d=050). Likewise, boys in flipped sections who completed all online learning activities showed a mean gain of 0.69 (69%), while those in traditional sections showed a mean gain of only 0.50 (50%). This denoted a significant difference with a p-value of less than 0.001 and medium effect size of 0.63. Both genders showed significantly higher gains within the flipped sections, when accounting for learning activity completion (Table 4). However, this effect seemed to be most significant for boys.

Table 4. Gains by Gender.

Girls	**Boys**

	Traditional	*Flipped – Completed Learning Activity*	*Traditional*	*Flipped – Completed Learning Activity*
Mean	0.56	0.73**	0.50	0.69***
Stdev	0.37	0.31	0.39	0.28
n	83	65	61	51
d	-	0.50	-	0.63

Gains by gender, accounting for activity completion in flipped sections. LOS reflect t-tests between traditional and flipped students within gender categories. LOS reflect t-tests between Traditional and Flipped Students within gender categories.

When we examined students in flipped sections and accounted for their online learning activity completion, we found no differences between boys and girls. Likewise, when we examined traditional students we found no differences between the genders.

In summary, accounting for completion of all online learning activities, we noted both boys' and girls' gains were higher in flipped sections than in traditional sections ($p<0.001$), implicating the value of assigned learning activity completion in student performance. This finding suggests the effect of using a flipped approach was mediated by how students engaged in the activity. In a manner consistent with activity theory, the students' learning was not contingent on the presence of the technology enhanced approach, but rather on how the students used the technology, or tool.

QUALITATIVE FINDINGS

We used qualitative interview data to focus our analysis on possible reasons to explain the noted differences in gains, as well as to answer our research question about students' interactions with technological tools. Through coding the interview data, we found certain patterns and themes.

Our initial review of the data allowed us to code students' comments into one of three broad categories of talk—Experience with Flipped Instruction, Traditional Biology Class, and Ideal Classrooms (Table 5). Any instances of student talk that did not fall into one of these three primary codes were coded as Miscellaneous. No comments were classified into more than one of the four main coding categories. The Experience category included any instances of talk in which the students discussed specific, previous experiences with flipped classrooms, including, but not limited to, this study's treatment. The Traditional Biology Class category included any student descriptions of aspects of his or her current Biology class, including learning activities and homework assignments. The Ideal Classrooms category included any instances of student talk in which the student discussed his or her ideal or preferred Biology learning environment.

Table 5: Student Perceptions, as Coded into 3 Main Categories.

L1 Code	L1 Code Description	L1 N=	Example Quote
Experience with Flipped Instruction	Student talk regarding experiences with flipped classroom learning	**144**	'I found it much more easy to understand the video because if you miss something, you can always rewind and then you could take notes on that and you could just better understand it….'
Traditional Biology Class	Student descriptions or talk about typical biology class	**156**	'I think in biology, our typical homework assignment is basically reading and taking Cornell notes.'
Ideal Classrooms	Student talk about their ideal learning environments or classrooms	**81**	'I think do experiments because it's really helpful when you see, like let's say we're learning about DNA, right, it's really helpful if you see like how DNA's – how it looks…'

All student comments were first coded into one of three categories. Codes were mutually exclusive.

After the initial coding, we reexamined the data to discern themes within each of the three broad categories. Several interesting, recurring ideas emerged within each primary code. After thorough analysis, we established six different Level 2 codes within the Experience code, four Level 2 codes within Traditional Biology Class, and three Level 2 codes within Ideal Classrooms. Table 6 provides full descriptions and representative examples for Level 2 codes within Experience with Flipped Instruction, the category that became the focus of our analysis.

Table 6. Student Perceptions within the Level 1 'Experience' Code.

L1	L2	L2 Code Description	L2 N=	Example

Experience with Flipped Instruction N= 144	**Adaptability and Portability of Digital Tools**	Student talk regarding the adaptability and portability of digital tools, including being able to stop and start videos, watch videos from anywhere, and access multiple resources online.	**28**	'It also goes at your own learning pace, so you could stop it whenever you want, but also, you could keep going versus when you're in class– it goes at a certain pace and eventually, sometimes you get bored....'
	Interest and Motivation	Student talk regarding interest, attention, and/or motivation levels, in the context of flipped instruction.	**41**	'I mean for me personally I like watching videos: I find it more enjoyable to do. So like, *Okay, for my homework I have to watch this video and take a little online quiz.* I'm like, *Okay, that will be fun*, just watch a video…It got me more motivated.'
	Multimedia Nature of Digital Tools	Student talk regarding the multimedia nature of digital tools used within the activity	**21**	'Just like kind of seeing, being able to place pictures with messages, just knowing that what something you're learning looks like for me is a lot easier to remember….'
	Relevance to Daily Life	Student talk about the relevance of the flipped learning activity to their lives	**4**	'They had quotes from Star Wars and stuff and things that related to reality. So I could be like, *Oh, wait, I get that*. I connected more with it.'
	Positive Impacts on Learning	Student talk in which students discussed positive impacts of flipped instruction on learning.	**25**	'I definitely learned a lot more during the lecture at home because when he gives us textbooks and sections to read, it's kind of difficult for me to understand it, so it's much easier in video format 'cause I don't know, they're just much clearer.'
	Negative Aspects	Student talk about negative aspects of experiences with flipped instruction.	**28**	'Because in class, you go – when they teach it to you, they have more detail on it so you know more than versus like watching like a five minute video.'

Given the quantitative results, we chose to focus our microanalysis on key Level 2 codes within the broader Experience category, as we believe that these student comments help to explain the comparatively high learning outcomes of the flipped group and shed light onto students' use of digital tools in this learning experience. In particular, three dominant explanations for successful learning through flipped methods were noted: the multimedia nature of the online tools, the adaptability and portability of the online tools, and students' interest in and motivation for completing the activities.

Multimedia Nature of Tools

Many students cited the multimedia nature of the digital tools as helpful in their learning (Table 6). Often, student conversation described how engaging with the combinations of words with sounds and pictures in the video helped them to remember ideas. One student, Timothy, reported:

> Just like kind of seeing, being able to place pictures with messages, just knowing that what something you're learning looks like for me is a lot easier to remember, 'cause I can think, *Oh I heard this is a new word. I can just remember this picture to go with it, and then I can put the two together*. It's way easier for me.

Timothy described how the combined images and messages of the video could spur his memory in class—when he would hear a term, he could think back to the video, remember the image accompanying the term, and, thus, remember the concept. In a different interview Molly described:

> I could visualize it better—the information I got—better than I would have with the textbook. It's nice right-away information, whereas instead of having – to try to visualize what you read last night in a textbook or with your notes.

Molly noted that the combinations of words and images in the video allowed her to visualize the information more easily, thereby supporting her connections in class.

Another aspect of the multimedia nature of video instruction that students cited as helpful to their learning was the ability to see a process unfold through the images and words of the animation. Natalie stated, ‘I think the video was good because it was like, you could see an example happening,’ while in a separate interview, Leah compared learning through video instruction to learning through textbook reading, saying that ‘in the textbook, they might give you one example or not give an example at all, just they say for example, mitosis, what the process is, but in a video, they'll explain what mitosis is and they'll give an example.’ Both Natalie and Leah appreciated the examples given by the video and suggested that the ability to view these examples and processes happening through video tool supported their understanding.

Adaptability and Portability of Digital Tools

Many students also cited the adaptability and portability of the online learning activities as helpful to both their ability to complete the task and their learning from them. In particular, manipulating the video allowed students to review information that they did not thoroughly understand upon the initial viewing. When asked about aspects of the video that supported his learning, Ben responded,

> I [stopped to press rewind] like three times when I missed like information and it's much easier for me because during class, there's a bunch of students and they all miss different points, but when I'm sitting down or lying down on my computer listening to the video, I can easily just go back, rewind and like pay more attention and hopefully understand the topic that they were talking about that I missed before.

Comparing learning from the video to learning in class, Ben made the point that the ability to manipulate the video allowed for multiple types of engagement with it and greater understanding than in class. The contrast he offered suggests that classrooms with many students make providing every student an opportunity to review the information difficult.

In the same group interview as Ben, Jena agreed with his point, saying:

> Yeah, and [the video] also goes at your own learning pace, so you could stop it whenever you want, but also, you could like keep going and like versus when you're in class, you – it goes at a certain pace and like eventually, like sometimes you get bored, so you like zone out and you don't take notes, but in the video, you could stop whenever and like take notes and then like stop again to review it.

In addition to Ben’s point about being able to review material multiple times with the video, Jena noted that, because the video went at her own learning pace, she avoided the ‘zoning out’ that occurs in class, which prescribes a pace for all students.

Also related to the portability aspect of the activity, many students commented positively on the fact that the online task could be done from many different locations. Several students reported that they had completed the activity on their phones from a car or bus, or from a computer at school or home.

Additionally, seven different students specifically mentioned the online submission of the activity as a particularly convenient aspect of the assignment. One student, Erin, reported the importance of ‘not having to worry about remembering [the assignment].’ Because the submission was online students lauded the convenience of not needing to put a piece of paper in their backpack or bring it to school.

Interest in Digital Tools

Many students also discussed their levels of interest in and motivation for engaging with the digital tools. Many students reported feeling more interested in the work, and therefore more motivated to complete it. One student stated:

> I mean for me personally I like watching videos: I find it more enjoyable to do. So like, *Okay, for my homework I have to watch this video and take a little online quiz.* I’m like, *Okay, that will be fun*, just watch a video. And the video wasn’t droning on in a monotonous type style: it was very peppy and fun and it kind of helped me do the homework I guess. It got me more motivated.

Like several other students interviewed, this student described feeling more interested in completing an assignment that involved the digital tool of video as compared to more traditional tasks.

Some students reported on negative aspects of the online learning experience. Many of these complaints were related to the level of detail in the video—several students felt that it was not high enough for them to fully grasp the concept at hand. Ben described class as ‘definitely way more detailed’ as compared to the video lesson. Ana reported learning ‘less than [from] other homework assignments.’ Two students said that they preferred learning through reading text rather than watching a video. We see these negative aspects of the flipped experience as important to consider, and as helpful guides in considering future implementation of flipped classrooms.

DISCUSSION & CONCLUSION

This project sought to examine three vital questions. First, how is use of flipped instruction related to high school students' science learning? Second, in what ways do students interact with technological tools in flipped instruction? Third, what are students' reflections on learning using a flipped approach to science teaching? The mixed data sources affirmed what previous studies identified: flipped instruction has the potential to enhance students' science learning. However, the factor that appeared to mediate the benefit of learning with flipped instruction was students' engagement with the technology beforehand. Consistent with an activity theory perspective, the technology fostered learning when it was paired with activities that helped to connect cognitive activity with useful socially situated tasks within a community of distributed expertise (Cole, Engestrom, & Vasquez, 1997; Roth & Lee, 2007). Finally, students' reflection of their experience with learning science via flipped instruction focused on how the digital, multimedia tools helped to initiate the learning process. Together, the collective results of this study suggest that flipping instruction can be valuable if educators create learning contexts that enable all students to engage with all technological tools necessary to instruction.

The quantitative data suggested that students' learning outcomes were enhanced with flipped classrooms, as compared to traditional pedagogical models. Flipped classroom students showed a mean gain that was significantly higher than that of the traditional students ($p<0.05$). These results give us confidence that those who experienced flipped instruction performed better on post-tests. When we compared flipped students who engaged with all online tools (71% gain) to traditional students (54% gain), we found that flipped students showed even higher gains at a greater level of significance ($p<0.001$). Not only does this finding further support the claim that flipped students gained more through instruction, but it also implicates the critical role of the digital tool component of flipped classrooms. This result further affirmed the need to distinguish between the effect of using the technology and the careful analysis of how using the technology differently might impact learning. Likewise, the significantly lower gain of flipped students who did not complete all parts of online learning activity ($p<0.001$), as compared all other students, further highlighted the importance of the technological tools. Thus, if we do not carefully design activities that engage students and ensure their completion, potential negative impacts of flipped instruction exist. By contrast, this study also demonstrates how students' learning can be enhanced when flipped instruction is paired with sound pedagogy and easy access to digital tools.

Gender and Learning

Analysis of gains by gender group revealed some interesting trends. At first, the flipped treatment appeared to positively influence only girls, as boys showed no significant differences in gain between flipped and traditional settings. However, when we narrowed the analysis to include only the flipped students who completed all parts of the online learning activity, both boys and girls showed significantly higher gains in flipped sections than they did in traditional sections ($p<0.001$; $p<0.01$). Furthermore, whereas flipped girls had shown higher gains than boys when all flipped students were included, there were no statistically significant differences in gains between the genders when we examined only flipped students who completed the online activity. These findings could reflect a stronger influence of engaging with the technology on boys' learning or a higher proclivity by boys to not complete out-of-class work. In either case, as schools move toward implementation of flipped classrooms, they should be cautious any differential engagement with technology between boys and girls.

These results offer a tenuous insight about potential of flipped instruction to positively influence student learning, depending on engagement with online, digital tools. Our data offers additional empirical insight to the growing data that suggests that flipped instruction has the potential to be effective. However, the data shared also offer a subtle warning to pay particular attention to the human element technology—learners' interactions and engagement with the tools purported to support their learning. These results also suggest that focusing on the pedagogical and logistical aspects of flipped instruction emerge as vital factors in determining whether the flipped approach can become an effective component of contemporary STEM teaching. Any broad implementation of flipped instruction at the secondary level should actively consider effective ways to encourage, scaffold, and support engagement with digital tools outside of class.

Why Could a Flipped Classroom Be Effective?

Interviews allowed us to explore students' perceptions of the flipped experience. The qualitative data suggested students offered three explanations for the successfully bolstered learning outcomes. The data implicated the role of (1) the multimedia nature of the tools, (2) the portability and adaptability of tools, and (3) heightened student interest in the online learning activity.

Engagement with the online activity involved a combination of images with spoken words and written text that allowed students to develop an understanding of the material. Because the activity offered means of learning through multiple pathways, according to Mayer's (2009) 'dual channel' assumption, students were better able to process and store the incoming information. Watching the video, students could immediately visualize the complex concepts of meiosis while also processing the information aurally. This subtle difference could have a significant impact. For students learning for the first time at home, they were introduced to the phenomenon by seeing the simulation and hearing the explanation simultaneously. By contrast, students in traditional sections were not afforded the dual channel experience. Additionally, the multimedia activity positioned the students as active learners who engaged in cognitive processing to construct a coherent representation of the ideas being learned (Mayer, 2009; Mayer, 2005; Chi et al., 1989). This opportunity for processing emerged from learners' engagement with the digital tools. From an activity theory perspective, uptake and use of the tool mediated the learning of students who engaged with it.

Limitations

Certain limitations should be considered with this study. Most of the participating students had experienced flipped instruction only a few times prior to this study. Thus, the use of flipped technology was likely a novel experience for students. Students' self-reported high levels of engagement could thus have been a product or partial product of the novelty of an online, multimedia assignment. Additionally, the enhanced learning outcomes noted for flipped students could be related to higher levels of engagement. The assignment's novelty and its brief implementation timeframe of 1 to 2 days likely contributed to such heightened engagement. Moving forward to continue this line of inquiry, we should consider a second iteration of the study that extends for a longer implementation period. In doing so, students would likely grow accustomed to it, thus diminishing effects of the method's novelty.

Additionally, the reliability of the pre- and post-tests revealed only moderately reliable scales (.67 & .70 for pre- and post-test, respectively). However, the assessment questions on both the pre- and post-tests were adapted and modified from sample items within the Holt Biology textbook. This modification was a necessity based on using the schools' existing biology curriculum. Items on both assessments were checked repeatedly to ensure that they aligned with each other as well as with the key learning objectives of the lesson. We believe that they reflect a valid and accurate assessment of students' knowledge.

Furthermore, while this study examined a diverse group of approximately 300 students, the sample could not capture the extremely high diversity of students in high schools across the US. Further inquiry into flipped instruction would benefit from targeting different populations of even greater diversity. Additionally, future research should explore other educational contexts, including urban and rural classrooms, as well as more homogenous classrooms typical of other areas of the country. Despite the limitations, we believe that this study offers insight into the role of flipped instruction in high school science classrooms.

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