Weaving together media, technologies and people

Students' information practices in flipped classrooms

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Abstract

Purpose – Students in flipped classrooms are challenged to orchestrate an increasingly heterogeneous collection of learning objects, including audiovisual materials as well as traditional learning objects, such as textbooks and syllabi. This study aims to examine students' information practices interacting with and synthesizing across learning objects, technologies and people in flipped classrooms.

Design/methodology/approach – This grounded theory study explores the information practices of 12 undergraduate engineering students as they learned in two flipped classrooms. An artifact walkthrough was used to elicit descriptions of how students conceptualize and work around interoperability problems between the diverse and distributed learning objects by weaving them together into information tapestries.

Findings – Students maintained a notebook as an information tapestry, weaving fragmented information snippets from the available learning objects, including, but not limited to, instructional videos and textbooks. Students also connected with peers on Facebook, a back-channel that allowed them to sidestep the academic honesty policy of the course discussion forum, when collaborating on homework assignments.

Originality/value – The importance of the interoperability of tools with elements of students' information space and the significance of designing for existing information practices are two outcomes of the grounded theory approach. Design implications for educational technology including the weaving of mixed media and the establishment of spaces for student-to-student interaction are also discussed.

Keywords Activity theory, Personal information management, Video-based learning, Flipped classroom, Information practice, Annotation and note-taking

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Introduction

An increasing number of university courses choose to engage students with instructional videos and expository course materials outside (and often before) class, so instructors can apply interactive teaching strategies in the classroom, commonly termed “flipped classrooms” (Bishop and Verleger, 2013). As a significant amount of learning takes place outside the classroom, flipped classrooms make heavy use of diverse online learning objects, in addition to traditional ones. These include, but are not limited to, textbooks, discussion forums, learning management systems, online homework systems, discipline-specific tools (such as simulations or source code repositories) and social media back-channels introduced by students (Gikas and Grant, 2013; Li and Greenhow, 2015; Lin *et al.*, 2013). Common to most flipped classrooms is the reliance on video as a medium that replaces traditional lecturing (Tucker, 2012). The heterogeneity of learning objects results in a complex information space.

This paper is concerned with students’ information practices for interacting with and synthesizing across learning objects, technologies and people in flipped classrooms. Orchestrating these learning objects and tools is especially challenging given that semantic information often spans learning objects, technologies and people. For example, a topic can be covered by the textbook, lecture and homework. By using the term *orchestrating*, we are describing a student’s ability to make sense of diverse types of information and resolve their information needs by using or creating various types of information. In many ways, the ability to orchestrate is closely tied to a high proficiency in digital and information literacies. Synthesizing information spread across learning objects is a challenging task for students (Barzilai *et al.*, 2018) and an important information literacy to develop (OECD, 2018).

In this paper, we focus on how students annotate and take notes while watching instructional video, and the ways in which they collaborate in social network back-channels. We build on earlier work on note-taking and paper notebooks to better understand how people make connections between information within mixed media collections of learning objects. The culmination of these lines of inquiry led us to explore the following research question:

RQ1. How do students interact with the diverse and distributed human, material and socio-technical elements of their information spaces?

When we zoom out from a perspective that focuses on a specific medium or tool, we can elicit new insights into students’ information practices and spaces, grounded in students’ experiences in flipped classrooms. Such insights provide meaningful input for the design of processes and technologies that support students in their learning.

Background

Information orchestration in flipped classrooms

Taking a socio-constructivist view, learning is a process of meaning-making that is mediated by learning objects and peers (Duffy and Cunningham, 1996). As such, learning is the product of the interactions between learners and their environments. Notably, one important aspect of learning is the ability to synthesize information (Bloom *et al.*, 1956). However, synthesis of information is very challenging (Goldman *et al.*, 2012). Synthesizing is especially challenging in learning situations: learners are required to not only apply productive information literacy skills but also apply these skills to materials that are new and challenging for them.

A significant focus has been given to the synthesis of textual information. Many of these studies look at note-taking practices (Schraefel *et al.*, 2004; Shankar, 2007; Tabard *et al.*, 2008;

Yeh *et al.*, 2006) and the affordances of paper notebooks (Adler *et al.*, 1998; Guimbretière, 2003; O'Hara *et al.*, 1998; Sellen and Harper, 2001) in making sense of information. However, this work focuses mainly on processing of textual information.

Synthesizing information across media types introduces additional challenges. Information needed by learners can cross-cut diverse sources of information. For example, an online video may be used to demonstrate text in a textbook, but both are required to be able to solve a problem in a homework assignment. Hence, a learner ends up needing mechanisms to connect semantic information presented in separate media, including the growing types of non-textual media (Mayer, 2019). According to cognitive load theory, this relationship creates high element interactivity and subsequently high cognitive load (Sweller, 2010).

As the use of non-textual course materials is growing, including audiovisual learning objects, there have been calls for the examination of new media literacies to facilitate learning (Koltay, 2011; Thomas *et al.*, 2007). Indeed, much work has focused on the use of non-traditional learning objects in flipped classrooms, such as video (O'Flaherty and Phillips, 2015) and social media (Barhoumi, 2015; Rambe, 2012). However, scholars typically investigate the creation and consumption of any single medium in isolation of other media, falling short of exploring how students make connections within heterogeneous information spaces and limiting the ecological validity of the findings. To manage their learning in these scenarios, learners are required to regulate their learning. From an information processing perspective, learners apply a variety of strategies that allow them to construct relevant schemas of knowledge. The application involves three main phases: defining the task, setting goals and plans and enacting tactics (Winne, 2001). These complex actions often benefit from relevant tools. However, currently, there are no common tools for orchestrating diverse information sources. For example, presently, most learning objects cannot be exported or curated in a meaningful way across genres. As a result, the labor of orchestrating information across such a wide variety of resources puts a burden on learners. Here we focus on ways in which learners manage this complex task.

Methodological approach: grounded theory

As the goal of our study is to bridge the existing gaps in empirical knowledge and theories, our mode of inquiry is exploratory, generative and discovery-based. Consequently, we used the ground theory approach to systematically collect and analyze qualitative data from a group of diverse, purposefully selected informants sampled from targeted social settings in pursuit of generating a reportage supported by new theories and thick descriptions. Grounded theory has been used in the fields of education and information science for decades (Hutchinson, 1986; Seldén, 2005).

Following the arguments of Glaser and Strauss (1967) regarding the benefits of validation criteria and systematic analysis, we identified elements of students' information spaces and shared information practices in flipped classrooms, discovered relationships between these elements, documented thick descriptions and systematically constructed a theory of interoperability of educational technologies.

Since the publication of the original grounded theory text *The Discovery of Grounded Theory* (Glaser and Strauss, 1967), three traditions of grounded theory have emerged: classic, Straussian, and constructivist grounded theory. In this paper, we follow the Straussian grounded theory approach. Each tradition is considered under the umbrella of grounded theory because they all make use of the concepts of theoretical sampling, saturation and comparative analysis as put forward by Glaser and Strauss (1967). In grounded theory, data collection procedures are not finalized at the beginning of the study because it is held that researchers should be responsive to gaps that emerge during the initial data coding and analysis. These gaps indicate how the direction of the study should be changed and which data should be collected. Glaser and Strauss call this theoretical sampling. The process of theoretical sampling continues until no new data emerge from the sample, which Glaser and Strauss call the point of saturation. The concept of constant comparison is also key to grounded theory, which is the process in which data are coded with a conceptual label. These codes are then compared with one another and grouped into emerging categories. These categories are then compared with each other. The three traditions of grounded theory are similar, in that they all draw on the concepts of theoretical sampling, saturation and comparative analysis put forward by Glaser and Strauss (1967).

However, the three grounded theory traditions deviate from each other with respect to their coding procedures and timing of the research literature (Kenny and Fourie, 2015). Classic grounded theory offers the notion that a theory naturally emerges during data analysis. In this tradition, a latent theory is thought to be discovered from the data. This position has been criticized for overlooking the biases researchers bring to their work (Charmaz, 2006). The Straussian grounded theory emphasizes the creation of a theory by following a set of rules. Strauss and Corbin (1990) presented these rules in a four-stage coding framework, which were intended to limit the bias of researchers. The constructivist grounded theory suggests a more flexible, open-ended approach to coding than either classic or Straussian grounded theory, to construct a theory. The lack of rules in constructivists grounded theory has been criticized by Glaser (2002) for providing researchers with too much ability to re-interpret the experiences of their participants.

The classic, Straussian and constructivist grounded theories offer different approaches to the use of research literature, with two broad approaches emerging:

(1) delaying the research literature review until after data collection and analysis begins; or

(2) conducting a review of the research literature before the study, and then expanding upon this preliminary review throughout the data collection and analysis process (Giles *et al.*, 2013).

The classic grounded theory takes the first approach, delaying the research literature review, whereas the Straussian and constructivist grounded theories can take either the first or second approach. We purposefully deviated from the typical structure of an *Information and Learning Sciences* paper by addressing related work at the end of the paper, because grounded theorists often direct researchers to survey the research literature after the completion of data collection and analysis. This approach helps prevent the researchers' inductive reasoning process from the bias of previously registered concepts (Glaser and Strauss, 1967). Thus, the organization of the paper better reflects our work process, in which data collection and analysis were followed by generative interpretation, which, then, was contextualized in the related work.

In the next section, we describe our methods. Following that section, we present our findings in two main areas: interactions with information objects and interactions with peers. Then we discuss the design and theoretical implications of our work, and ground these findings in the existing research literature.

Methods

In the following section, we review the methods of the study. We describe the two flipped classrooms from which we recruited students. Our sampling procedure is discussed, and descriptions of participants are provided. The procedure of the study is described, including a review of the data collected, and how they were analyzed.

Courses, students, and sampling

We conducted open-ended, semi-structured interviews with 12 undergraduate students in two flipped engineering courses at a large research university in Canada: an Applied Science (AS) course, a first-year course on coding with the C programming language, with 315 students and an Electrical Engineering (EE) course, a second-year course on electrodynamics, with 201 students. Of the 12 interviewees, 7 were enrolled in the AS course and 5 in the EE course.

Both courses required students to learn new information at home using video-based learning objects. The AS students were expected to watch videos every week in preparation for class (13 videos in total, of 8 ± 3 min each) and were quizzed on the corresponding video content later in class using graded-for-participation clicker questions, using iClicker, an electronic, in-class polling system. Similarly, the EE students were asked to watch one to two videos each week (15 videos in total, of 8 ± 4 min each), which were accompanied by three online, graded questions as preparation for class, delivered using the course learning management system.

A call for interviewees, inclusive of all students enrolled in the flipped classrooms, was shared through a learning management system by their instructors (Table I). Participants were compensated for their time with a C$20 honorarium.

Students in the AS and EE courses used a variety of learning objects (Table II) and tools, including ViDeX (Fong *et al.*, 2018), a Web-based video player that supports advanced features for annotation (e.g. temporally anchored highlighting, note-taking and tagging) and navigation (e.g. play/pause, fast-forwards and rewind; Figure 1).

Filmstrip and Transcript are two major navigation cues in the user interface that were specifically designed to provide students with visual and textual representations of the video content, respectively. The Filmstrip supports visual navigation of content through thumbnails. Students can hover their cursor over a thumbnail to preview the visual content

ID	Course	Notebook	Back-channel
P1	EE	Paper notebook	Yes
P2	EE	Paper notebook	No
P3	EE	Paper notebook	Yes
P4	AS	Paper notebook	Yes
P5	AS	Paper notebook	Yes
P6	AS	Paper notebook	Yes
P7	EE	iPad (GoodNotes)	Yes
P8	EE	iPad (Notability)	Yes
P9	AS	Paper notebook	No
P10	AS	Paper notebook	Yes
P11	AS	Paper notebook	No
P12	AS	None	Yes

Notes: AS and EE indicate the Applied Science and the Electrical Engineering courses, respectively. All but one participant reported taking notes for class – usually in a paper notebook. Most students also reported participating in a student-created Facebook back-channel for asking and answering homework questions with peers

Table I. Participants in our study were sampled from two undergraduate engineering courses of a specific interval of time. The Transcript enables text-based navigation of the content of a video. The Transcript allows students to read ahead or behind the playhead.

The annotation features are designed to support *active viewing* behaviors (Dodson *et al.*, 2018). Highlighting and note-taking are the major means for the students to interact with and personalize instructional video content. Students can highlight and take notes on both

Table II.
Instructors provided students with a variety of learning objects, including lecture notes/slides, readings, instructional videos and syllabi

	Course	
Learning object	AS	EE
Discussion forum	n/a	Piazza
Homework	Assignments shared via LMS	Assignments via WeBWorK online homework system
Instructional videos	Articulate and ViDeX	ViDeX
Lecture notes/ slides	PowerPoint slides in videos via ViDeX; solutions to in-class activities shared via LMS	OneNote notebook shared via LMS
Syllabus	Shared on learning management system (LMS)	Shared on LMS
Textbook	Assigned	Assigned

Note: These learning objects were mediated by a number of tools, such as discussion forums, online homework systems and learning management systems

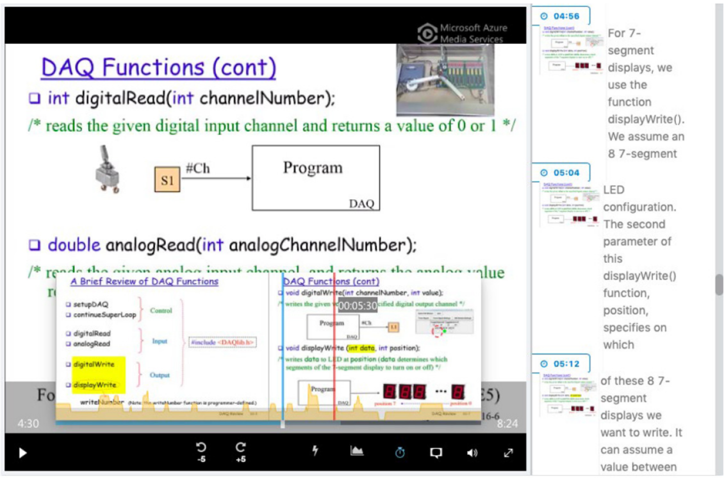


Figure 1.
Students had access to ViDeX, a Web-based video player that supports *in situ* annotation and note-taking

Notes: The ViDeX user interface comprises three elements: the Player, the Filmstrip and the Transcript. The Player is displayed at the top left, the Filmstrip at the middle left, the note-taking area at the bottom left and the Transcript at the right. Students can select intervals for highlighting using either the Filmstrip or the Transcript. At the bottom of the Filmstrip, a histogram displays the amount of time a student has watched specific parts of the video the Filmstrip and the Transcript. The two user interfaces are linked, so annotations made on the Filmstrip also appear on the Transcript and vice versa. All annotations are private – i.e. only visible to the student that created them.

Procedure

Participants were interviewed in a lab-based environment at the end of the semester and before final exams. The initial set of interview questions focused on participants' video-based learning experience and practices. Owing to the nature of constant comparison (Glaser and Strauss, 1967), the interview questions were adapted throughout the study in response to what we learned from participants' lived experiences.

To help participants share a detailed account of their learning, we began each interview with an artifact walkthrough (Raven and Flanders, 1996). We asked interviewees to complete two activities. First, we asked participants to log in to their ViDeX account and walk the interviewer through the instructional video they most recently watched, including why, when and how they watched it. Second, we asked participants to show us the learning objects they regularly use for class, including, but not limited to, their notebooks and textbooks. Photographs of these objects were taken with participants' consent.

The artifact walkthrough was used for two reasons. First, it reminded participants of their most recent experiences in the flipped classroom, allowing them to reflect on specific examples of their information practices and spaces rather than the lab environment where the interviews were conducted. Second, the artifact walkthrough acted as an icebreaker that eased interviewees into sharing additional interactions with learning objects, technologies and people.

Following the artifact walkthrough, we proceeded with a semi-structured interview. In total, the interview, including the artifact walkthrough, took about an hour.

Data analysis

Open coding, axial coding, selective coding and a conditional matrix were used as part of Straussian grounded theory (Strauss and Corbin, 1990) to create a theory. The interviews were audio-recorded, transcribed and coded in batches of two or three by the interviewer before the next set of interviews was conducted, to identify themes as they emerged and adapt the interview questions accordingly. We continued interviewing students until no new themes emerged. We reached theoretical saturation in thematic analysis after interviewing the 12 participants, collecting roughly 510 min of audio-recordings and 53 photographs of students' notebooks. The results of the analysis were discussed by two investigators for validation. Conflicts in code coverage were resolved by sessions of team-wide discussions.

Theoretical framework

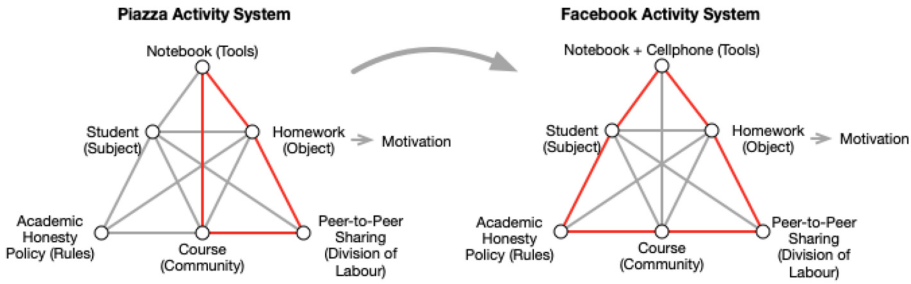
Following the grounded theory approach, we began our analysis without *a priori* hypotheses. As we coded the transcripts, though, we began to identify themes around students' interactions with class materials, their community of instructors and peers and tools as they learned in the flipped classroom. Acknowledging that students' learning environments are actively constructed, diverse, involve interdependencies between people and materials and constitute the spaces that in turn structure their learning led us to consider ecological metaphors of information space, such as Fidel (2012), Lloyd (2006) and Nardi and O'Day (1999). We chose activity theory (AT) (Kaptelinin and Nardi, 2006) as the frame for emerging themes, because participants' information practices appeared to be conducted within activity systems, in which learning objects and their relationships were transformed through students' goal-directed interactions with tools and people. Students' activities examined in this research are complex, involving the interrelationships between people, information, tools and tasks. We use AT as a tool to focus on the complexity of students' information spaces, with no value judgments of whether this is a challenge for students. AT also provided us with a vocabulary to describe the types of interactions students reported engaging in (Nardi, 1996).

In this paper's activity system (see Figure 2), *subjects* were students, *community* comprised instructors and peers and *tools* included information objects and systems. Key AT concepts include: the view that students' interactions with elements of their information space are goal-directed (*object-orientedness*), students' interactions with learning objects are mediated by tools (*mediation*), information can be learned or held in students' memory or communicated to or by students (*internalization/externalization*) and students and objects develop and transform over time (*development*).

In the following sections, the themes that emerged from our analysis of the interviews are discussed. We group these themes in two categories: students' use of learning objects, which were often mediated through their notebooks and students' interactions with peers, in particular interactions made through a social media back-channel.

Collecting, linking, and synthesizing

In flipped classrooms, information is spread across a collection of heterogeneous class materials of multiple types of media. Some learning objects, including notebooks, are used frequently and are at the center of students' information space, whereas other learning objects are used rarely and are at the periphery. We argue that all elements of the activity system are important to consider when studying students' information practices. The distributed and diverse nature of students' information spaces resulted in tensions and



Notes: Student liked sharing their homework with their peers, but Piazza, the class discussion forum, limited their ability to work together because of the academic honesty policy. The tool/community/object tension is highlighted in red on the left triangle. Consequently, students creating a new activity system, transitioning from the instructor-provided activity system (the left triangle) and created an alternative activity system on Facebook (the right triangle). This transition is represented by the arrow from the left triangle to the right triangle. The new activity system on Facebook allowed students to more easily collaborate on homework assignments; however, Facebook provided new challenges in sharing the contents on their notebooks with each other and adherence to the academic honesty policy of the course. The tensions between tool/community/object (i.e., sharing) and subject/rules/community (i.e. the academic honesty policy) are highlighted in red on the right triangle

Figure 2.
Students constructed their information spaces in response to challenges that limited their interactions with learning objects and people

breakdowns caused by the disconnections between learning objects and tools. A major challenge for students was to identify the relevant information and make connections between learning objects. To reconcile the amount, diversity and spread of information, notebooks played a central part of the students' information spaces, weaving fragments of information, extracted from text and video, and allowing students to save snippets of information for future use. All but one participant recorded snippets from class materials in a notebook. Students used their notebooks to synthesize, organize and orchestrate important information from multiple class materials in one place for use when doing their homework and preparing for exams, thus simplifying access, management of and navigation to information.

Notebook as information tapestry

Students' notebooks were the tapestry of their information spaces, weaving disparate learning objects together. This is an important practice for interacting with information. People need, Karger and Jones (2006) argue, "ways to unify, simplify, and consolidate information too often fragmented by location, device, and software application".

Participants used their notebooks to consolidate information from the learning objects, capitalizing on the flexibility of notebooks for consolidating information snippets from many media objects. All note-taking students, except Participant (P) 4, described the benefits of having all the important information in one place, rather than distributed across the available class materials. P3 said, "It's nice having everything in one place, because it's less things to lose. And it makes it easier to come back and you know where to come back to". P9 said:

> When I study for the finals [. . .] I just read through all my notes to refresh my head on this. And then I started doing practice problems. So, this way I don't have to watch all the screencasts. I can just read the notes.

The information provided students with an overview of the topics that had been covered in the course, but also synthesized information that they had identified as being important to their learning.

The flexible referential affordances of the notebook offered great interoperability for connecting diverse types of information. In our interviews with participants, we identified a number of learning objects that they made use of throughout the semester including, but not limited to, syllabi, textbooks, instructional video, previous homework assignments, handouts, notebooks and discussion forums. In addition to the diversity of learning object types, the sources of the information are also varied. Some learning objects are created by the instructor (e.g. syllabi, course websites, instructional video), others are created and maintained by the students (e.g., notebooks, homework assignments), and some may be the outcome of a co-construction process, whether synchronous or asynchronous (e.g. discussion forms, social media). Co-constructed learning objects often have layers of information, for example, when an instructor provides feedback on a solution created by a student in response to a question in the textbook. In this context, we argue it is important to ask to what degree students' learning is an interactive and iterative process, involving peers and instructors, and the role their personalized record of learning plays in mediating interactions between these different actors. Students with electronic notebooks, in particular, were able to easily reuse their notes by copying and pasting content from one page to another. P7 and P8 created information tapestries comprising many learning objects in single page of their notebook (Plate 1).

While it was not always easy for students to link between analog and digital learning objects, nor between text, images and video, students overcame this obstacle by using links that connected information from class materials and their notebooks. This was useful for not only recording information in their notebooks but also returning to the source of the information. When notebooks failed to provide students with sufficient information to complete their homework and exam preparations, participants moved from their notebooks back to their textbook, videos and other sources of information, often using the links and the traces they left behind in their notes and the learning objects.

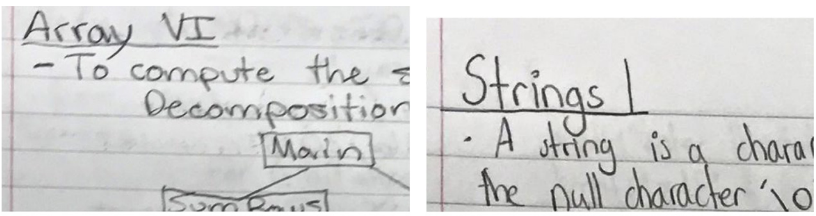
Notebooks were linked to learning objects through text cues that referred back to the source of the note. The specificity of these links varied, with some pointing to a whole learning object while others referencing a specific sentence in a text or timestamp within a video. Students often used the links they left in their notebooks, such as those in Plate 1, to move from their notebooks to the learning objects. All links took a kind of heading format and were often underlined, mirroring the style of hyperlinks on the Web. Students appeared to be using this formatting to facilitate re-finding of links in their notes.

We found that the content of students' notes was largely determined by their *task interpretation* (Butler and Cartier, 2004), or what students thought they would be evaluated on in their homework and exams. P7 said, for example, "What I usually write down is something that would help me solve problems [. . .] because our assignments, midterms, and everything, are all solely based on calculations".

In addition to leaving links in their notebooks, students also left traces in the class materials to "avoid the need to repeat the process by which the information was found in the first place" (Jones *et al.*, 2001). The applications of traces have been explored in the context of text-based information (Dourish and Chalmers, 1994; Kopak *et al.*, 2011; Wexelblat and Maes, 1999), but our work examines their use in multimedia information spaces. We found that students make use of their own traces when watching video as well. Annotations were applied to all available media types, i.e. text and video. P2, P4, P5 and P6, for example, annotated important information in the videos, including equations and step-by-step solutions to problems, by highlighting and tagging with ViDeX. P2, for example, said:

> I have tagged a few places where there's a whole page of formulas of an example of some sort. Just so that if ever I have to come back to these videos, to say review for an exam or quiz, I can always jump back to those positions really quickly.

The video-based annotations acted as bookmarks, guiding students' attention when returning to the class materials.



Notes: These links took many forms, but participants often labeled the sections of their notebooks corresponding to the name and number of the video in order to support navigation and re-finding. For example, P5 and P9 (left to right) wrote the title of the video the content was recorded from (i.e. "Array VI" and "Strings I")

Plate 1. Participants often added "links" to their notebooks, which pointed to the source of the information recorded in their notebooks

Non-use of educational technologies

The choice of annotation and note-taking tools provided students with a dilemma: to use medium-specific tools, such as ViDeX, or to record their notes in their notebooks. Students chose interoperability over medium-specific tools (i.e. notebooks rather than ViDeX).

While video players have been designed for video annotating and note-taking (Dorn *et al.*, 2015; Glassman *et al.*, 2015; Mu, 2010), these studies do not explore how note-taking also occurs outside of the video players and are, consequently, lacking a holistic picture of the learning objects and tools at students' disposal. In the previous section, we identified an under-explored aspect of note-taking and notebooks that was crucial for students in orchestrating information from many media to create their information spaces: weaving together diverse and distributed learning objects. By embracing a tool for each medium, threads of information would be separated by media.

The importance of the interoperability of educational technologies was highlighted in our observations of students' resistance to tools that provided them with limited control over the content and their annotations and notes. Students were hesitant to shift their existing note-taking practices to a proprietary annotation and note-taking tool, especially because students' existing notebooks enabled them to take notes of video. Students expressed concern about the ownership of their annotations and notes. P5, for example, said, "The one thing that I'm kind of—like not weary about—but it's like if something happens to [ViDeX], what will happen to all my notes?" Student wanted control and ownership of their notes.

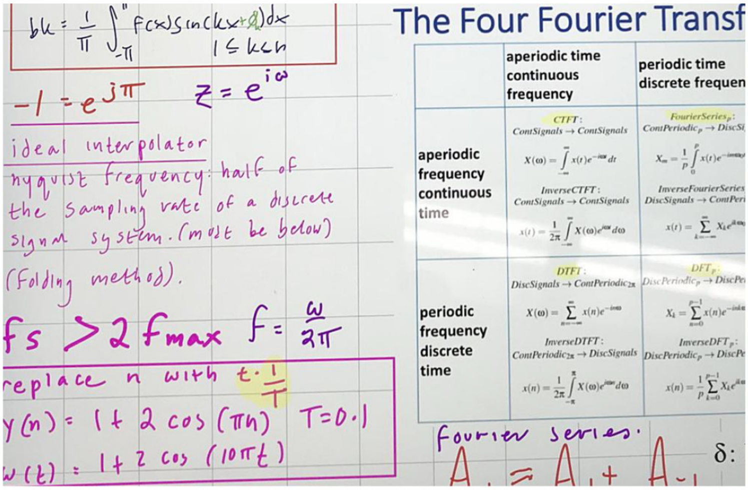
In our conversations with participants, we learned how their way of taking notes in the flipped classrooms was influenced by their existing annotation and note-taking practices. While students could benefit from the ease of using a medium-specific tool by embracing ease of full adoption of ViDeX, they preferred to continue using their own means for constructing a personal information space of their own, designing their own workflow for managing their information. Students preferred their notebooks to medium-specific alternatives, because they were able to weave multiple threads of information together into an information tapestry with their notebooks. This resulted in students' frequent learning practice of identifying, extracting, and weaving (i.e. *externalizing*) information snippets from the learning objects in their class materials.

The importance of interoperability applies not only to ViDeX. Students described similar resistance to other media-specific technologies for annotating. P8, who used an electronic textbook and corresponding electronic reading app, said:

> I use the iPad and I will copy and paste [information] if I need to make a note [in my notebook]. [. . .] I'll usually do this if I'm doing a [homework] question from the textbook. I can paste the question and all of the relevant equations right there [in my notebook] (Plate 2).

Total adoption of ViDeX or a digital reading app would have caused a conflict with how students typically record and manage information from class materials and resulted in fragmentation caused by the limited interoperability of elements in their information spaces. Consequently, students resisted full adoption of ViDeX, and instead adapted it in ways that complement their note-taking practices through the placement of traces to guide their reuse of class materials.

Notebooks fulfilled an important function for participants because free-form inking, in particular, allowed them to leverage a greater breadth of expressions (Sellen and Harper, 2001) when, for example, writing notes on the content that appeared in the videos, which included equations, figures, and tables. For this purpose, the ViDeX annotation features were limited. There is a rich literature on the affordances of paper, which has identified the value of free-form inking, permanence of paper notes and ease and flexibility of paper use in



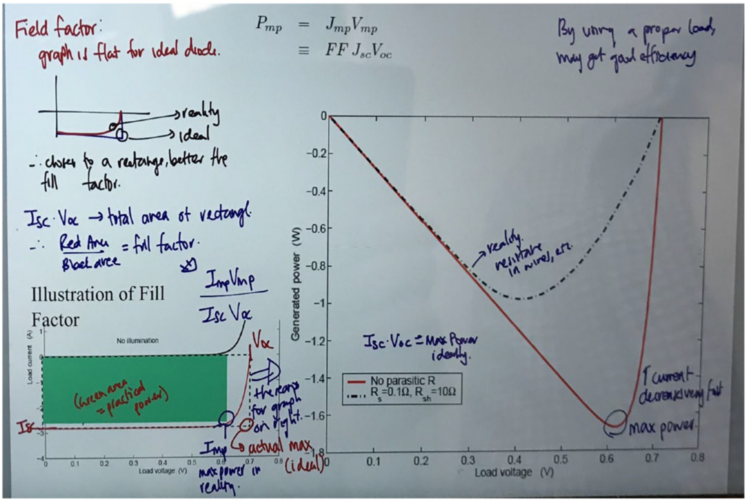


Plate 2.
Electronic notebooks allowed P7 and P8 to create information tapestries from existing notes and learning objects by weaving together information from multiple sources

Notes: P8 (pictured top) copied and pasted formulas, originally from the instructional videos and the textbook, from her notebook into a single cheatsheet page for use when doing homework and studying for exams. P7 (pictured bottom) used a similar technique for combining clippings from multiple information objects, often copying and pasting the content of multiple PowerPoint slides on one notebook page and then annotating the information

multiple contexts (Adler *et al.*, 1998; Guimbretière, 2003; Marshall *et al.*, 1999; O'Hara and Sellen, 1997; O'Hara *et al.*, 1998; Sellen and Harper, 2001). P1, P3, P5, P7, P8 and P9 commented on the difficulty of typing notes on this content in the ViDeX text box. P1, for example, said "I think because of the nature of this course, where it involves a lot of drawings and even equations sometimes, it is hard to write it on a screen". There was no way to mark up, with e-ink, much of the visual content of the videos, leading participants to use their notebooks.

The focus on students' annotation and note-taking practices has so far explored their interactions with class materials, often *mediated* through paper notebooks. However, students also regularly engaged with their instructors and peers. The next section describes students' interactions with their community, including the tensions in *rules* and *division of labor* that *mediated* these interactions.

Social interactions within the information space

In addition to interacting with learning objects, students regularly interacted with other people. In class, students worked together, with the help of their instructor, on worksheets. At home, students continued to interact with their instructors and peers through Piazza, the course discussion forum. The academic honesty policies enforced on Piazza by the instructors, however, prohibited explicit answer-sharing. Students found these policies too strict, and participated in a self-organized Facebook back-channel. While communicating via Facebook resolved the *student/rules/community tension*, it presented new challenges in communicating due to the fragmented nature of the learning objects. In this section, we explored the nature of the Facebook back-channel, including why it was created, how participants made use of it and the difficulties they faced in communicating through social media.

Bypassing academic honesty policies through a social media back-channel

Students used social media, Facebook Messenger in particular, to engage in collective problem-solving when doing their homework. While, the AS and EE courses included a discussion forum, Piazza. Most of our participants reported lurking on Piazza to monitor posts and replies by their peers and instructor. However, all but three participants (P3, P8 and P11) reported a preference for communicating with each other via social media because of the strict rules of the academic honesty policy, which limited students' interactions with their peers and instructors on Piazza (Figure 2). In response to this *student/community/division of labor tension*, students used social media as a back-channel to work around the academic honesty policy. P8 said:

> People are much more inclined to really provide a detailed solution on Facebook, because the professor isn't going to get on [Facebook] and say "Hey! This is not good, because you're supposed to solve it yourself." But if you really have no idea [how to do the homework], then you should go to Facebook and ask.

Facebook allowed students to ask and answer questions about their homework, like Piazza, but also allowed the sharing of answers.

There was a sense of community between students participating in the group chat, which motivated the reciprocal sharing of homework answers. P4 said, "We have massive undergraduate group chats. There's one called 'First-Year Engineering' and it's like 300 kids are on it". A *rule* of the Facebook group chat dictated that only students could participate, leading to the expectation that students could engage with their peers. This meant that students were not monitored by their instructor and expected that all their questions and answers were relevant to everyone else in the group chat. P4 continued:

> It's good because you can just ask this huge collective of people [for help]. [. . .]. We're perfectly fine sharing answers with each other or telling someone how to do a question or what not. [. . .]. We're suffering together, so it kind of bonds us. So that's why I like how Facebook group chats

> work, because we [ask our question through] the group chat and then someone helps you just out of their good will.

Facebook was used by students, rather than another social media service, for two primary reasons: first, its popularity among the students and second, its design allowed students to reference a record of their communication after their conversation had ended. While students described using other social media services in their day-to-day communications, including Snapchat (P5, P6, P8, P10), WeChat (P12) and WhatsApp (P8), most students were active Facebook users. Facebook had reached a *critical mass* (Ackerman, 2000) that other services had not, leading students to use Facebook. P5, said "I never had Facebook, actually, until this year. I got Facebook because of the group chat feature. [. . .] It's because everyone already had it". Similarly, P12 said, "I use [social media] because [my peers] use [these services]. [. . .] I don't think I choose [these social media services] by myself. [. . .] You're forced to use them". The popularity of Facebook pushed students who may otherwise not use the service towards using it.

Facebook was also used because it provided a record of the peer-to-peer communication, which not all services do. P8 said:

> Other social media would just not really support [group chat]. Snapchat would be kind of weird, because it would just disappear after, so you couldn't go back and look at it.

In addition, P6 said:

> It's easier [to use Facebook Messenger]. For example, Snapchat: the message goes after you've closed it, so you can't really refer to what you guys are talking about and explaining. Since in [Facebook] Messenger you can go back and see 'Oh, this is what they said'.

While the value of ephemerality in everyday, mundane conversation among close friends has been recognized (Xu *et al.*, 2016), students returned to their Facebook group chats throughout their homework session, requiring a more permanent record to be referenced multiple times.

Divisions of labor in students' collective problem-solving

To complete their homework, students worked together by sharing answers to homework. When communicating via Facebook, students requested help on specific homework assignments and shared photographs of completed problems written in their notebooks. In AT, this is described as a *division of labor*; however, peer-to-peer sharing was not coordinated *a priori*. We will adopt the term "division of labor" to describe students' collaboration, with the recognition that students were not explicitly, for example, dividing up questions to the latest homework assignment. The term, we hope, is true to the general nature of students' cooperative behavior and will be useful to subsequent researchers as we consistently use the AT vocabulary to describe the context of the students information practices that they self-reported in the interviews. Participation occurred on an as-needed basis rather than a regular divide-and-conquer approach, where students are each assigned a problem of the homework. P8 said, "The questions on the group chat are usually 'I don't know where to start even' and then the answers are usually the full solution". On Facebook, most answers to questions about the homework were the solution to the problems. Students were not teaching each other, but rather just sharing answers. This is effective for the short-term objective of completing the homework, but not the long-term objective of learning about the topic of the course.

The question asking and answering on Facebook, was not balanced. In our interviews with participants, it was clear that some students were more likely to ask or answer homework-related questions on social media than others. Between students there was a sense that no individual should be responsible for going above and beyond in their efforts to answer questions. P7 said:

> Even if we do ask [a question], we know that we are all too busy to explain every single question. "So, here's my work and this is enough work I'm giving you. You do it. If you don't understand, I don't know what to do for you."

While students felt a sense of community and a general desire to help each other, they did not have the time to walk their peers through solutions step-by-step. Consequently, it was common for students to provide full solutions to homework problems without further explanation as to how the solution was derived.

Sharing answers on Facebook presented a challenge for students. All students, but P7 and P8, maintained analog notebooks, but Facebook is a digital communication technology. How did students share their homework? When asking and especially answering questions in this information channel, students needed to transfer paper information via a digital channel, resulting in an interoperability problem (Figure 2). The solution seven of the eight students used to resolve the *rule*, *community*, and *division of labor* tension was to take pictures of their homework in their notebook using their cellphones and then sharing those pictures with their peers by uploading them to Facebook Messenger. While full-page pictures of an equation being solved step-by-step may provide the most context of the problem at hand, students were interested in focusing on the specific point of confusion. Consequently, students occasionally annotated the screenshots, adding text and shapes to emphasize the important parts of the image.

Theoretical outcomes and implications for design

The results of this study contribute to the understanding of the tensions and breakdowns students face when interacting with heterogeneous information collections, and points toward a need for systems that are designed to help weave the fragmented learning objects. Grounded theory often produces a theory, and in this study, we developed a more nuanced understanding of the importance of interoperability of information, people, tools and especially existing practices in the design and deployment of education technologies. We observed a number of information practices for managing heterogeneous information collections, including the use of cross-media tools, linking, tracing and constructing information tapestries. The need for interoperability was highlighted in this study, especially through students' resistance to tools that only worked with one medium (e.g. ViDeX). Educational technologies should be designed for multimedia information tapestries, sharing with peers, and with existing information practices.

The information snippets students extract from learning objects may be further enriched, for example, by providing more than just single-medium representations of the content. In the case of video, the clipped content could support full audio and video playback from students' notebooks, rather than requiring students to access their computer and log in to ViDeX or copy the content into their paper notebooks. Electronic notebooks should work with images, text, audio and video, as these are the types of media available to people at school, work and home. We found that sharing the contents of notebooks was also important. This interoperability between technology and other elements of the information space, is key to tool acceptance and use. ViDeX lacked the easy exchange and transfer of information between its database and the other types of information and tools that students use. Consequently, students did not add their own information to ViDeX, preferring to annotate and take notes in their notebooks.

The centrality of the notebook in students' information practices suggests that educational technologies should integrate with, rather than displace, existing annotation and note-taking practices. We saw many students resisted ViDeX because they had existing information practices that would be displaced if they only used ViDeX for video annotating and note-taking. Interestingly, we saw the adoption and adaptation of the tool to supplement existing note-taking practices, including when students left traces in the instruction video using the ViDeX highlights, notes and tags to aid re-finding. Students also created links from their notebooks to the learning objects. Educational technologies should be designed in ways that work well with existing information practices.

From the students' perspective, there is also a need for a sanctuary space where they can converse about course content without intervention of their instructor, such as students working together without their instructors' supervision. When providing such an environment, in the context of schoolwork, there needs to be support and mechanisms for more nuanced code of conduct and data-sharing policies, which would allow students to help each other without cheating. As we have seen with ViDeX and the course discussion forum, a major difficulty when introducing a new technology into the information space is the interoperability with existing learning objects and a pre-emptive effect of tools that have gained a critical mass that suggests a critical mass of students need to buy-in to a service before students make regular use of it.

Situating findings in previous work

Our novel findings regarding the hypertextual nature of notebooks (digital and electronic) and students' active social role in constructing their information spaces can be situated in previous work on flipped classrooms, the affordances of paper and notebooks and the use of social media by students.

Activity theory and flipped classrooms

A benefit of our application of AT in this study is that it promotes a more holistic understanding of students' interactions within activity systems. However, the few studies of flipped classrooms that have taken an activity theoretical frame have not explored students' interactions with the diversity of media that are common in today's classrooms. For example, the tensions and challenges *instructors*, rather than students, face when teaching in flipped classrooms have been investigated (Bingham, 2016; Liu and Feng, 2015). The students' perspective on interacting in such environments was reviewed by Wood *et al.* (2016), focusing on the integration of AT and active learning, but did not identify the difficulties students face managing the information snippets from heterogeneous class materials available to them in flipped classrooms or their note-taking practices. Others have explored the use of social media as a *mediating* tool in flipped classrooms, including the use of Facebook (Rambe, 2012) and WhatsApp (Barhoumi, 2015); however, in these studies, instructors initiated and monitored the application of social media for use by their students. Again, we found that students build their own grass roots community precisely because it is beyond the view of their instructors.

Notebooks for personal information management

Students used a notebook for personal information management (PIM) by "finding, keeping, organizing, and maintaining information" (Jones, 2008). There is a small body of literature on students' PIM (Mizrachi and Bates, 2013); however, these studies have focused on how students arrange the physical spaces where they study, not the construction of notebooks.

The practice of annotating and note-taking has been previously studied (Adler *et al.*, 1998; Mackay *et al.*, 2002; O'Hara *et al.*, 2002; Schraefel *et al.*, 2004; Shankar, 2007; Tabard *et al.*, 2008; Yeh *et al.*, 2006). This work has investigated a variety of academic and professional (e.g. doctors, lawyers, and scientists) note-taking practices, contributing to understandings of how annotation and note-taking support active reading. Marshall's (1997, 1998) observations and interviews with students (1998) and her analysis of used textbooks provided insight into the forms and functions of annotations. O'Hara *et al.* (1998) observed that students write notes to focus their attention, better understand the material, organize information for later review and facilitate re-finding information.

Studies of annotation and note-taking for professional tasks may present situations that are different from the learning environments where students have unique motivations, needs, goals and tasks, nonetheless, parallels in our findings can be made at a high level. Tabard *et al.* (2008), for example, found that scientists keep a master notebook to organize what they have done and plan to do. The master notebooks "act as a reference point for handling and organizing the diverse strands of personal activity".

The activity of note-taking has also received considerable attention from scholars interested in the transition from paper to electronic texts (Adler *et al.*, 1998; Marshall *et al.*, 1999; O'Hara *et al.*, 1998; Tashman and Edwards, 2011). In the 1990s and 2000s, most of this work investigated how digital reading environments could provide support for the types of active reading that are common in student and professional workflows (Guimbretière, 2003; Morris *et al.*, 2007; Schilit *et al.*, 1998). Today, this work continues with scholars exploring how tools can be designed to support practices for active, constructive and interactive learning when interacting with new media (Dorn *et al.*, 2015; Glassman *et al.*, 2015; Kim *et al.*, 2014; Mu, 2010).

Students' use of social media

Previous work has noted the frequency of students' use of social media for messaging classmates (Grinter and Palen, 2002; Mizrachi and Bates, 2013; Stutzman and Kramer-Duffield, 2010). While services such as Facebook are frequently used for social purposes, such as maintaining an awareness of peers' whereabouts to coordinate social events (Barkhuus and Tashiro, 2010; Joinson, 2008), students also use social media for schoolwork. Grinter and Palen (2002), for example, explain that students often use social media, such as instant messaging (IM), for homework support. Grinter and Palen noted that the:

> [U]se of IM seemed to increase with age, with the younger teenagers valuing camaraderie while working on homework, and older teenagers either actively preparing for or already in college wanting to coordinate with friends on-line to improve course grades.

Previous research has investigated students' privacy practices (Stutzman and Kramer-Duffield, 2010); however, these studies of instant messaging practices did not identify students' use of social media as a way to work around policies for sharing information, as in this study. We also found that existing practices of using tools, both notebooks and social media, can pre-emptively limit the impact of learning objects and technologies. For example, some social media services were selected based on whether their platform had hit a critical mass of the student population.

Conclusion and future work

In this work, we provided a qualitative description of students' activities in flipped classrooms. We focused on the challenges students face as they learn with a heterogeneous collection of class materials, and interact with their instructor and peers while they work towards their learning goals. A major challenge for students is synthesizing and orchestrating information from disconnected learning objects and other people. By identifying the learning objects and people students interact with, and especially by focusing on the challenges students face and the workarounds they create, we establish grounds for future information and learning science research and development.

Note-taking is a critical learning practice that students regularly engage in to synthesize information from class materials and materials beyond those provided by their instructors. The many affordances of notebooks, especially the ability to collect snippets from heterogeneous learning objects and to add links from to the source of the information, were helpful for *mediating* students' interactions with diverse media represented in their information spaces and managing their personal information. The value of the notebook also increased throughout the semester, resulting in a personalized information tapestry to be consulted rather than returning to learning objects and refinding information. Social media was also an important part of students' learning, enabling students to engage with each other and work towards completing coursework. We found that the rules *mediating* students' engagement with peers was too strict in the course discussion forum, so they created their own community on Facebook Messenger. Social media presented its own challenges to students when they shared with their peers.

This study had limitations in its scope. The sampled population, first- and second-year, undergraduate engineering students, is not the likely representative of students of all ages and from all disciplines. The participants also responded to a class-wide advertisement, meaning that the voluntary nature of the study may have introduced bias in the types of students that were willing to participate in the study. Future work could investigate how students from other disciplines are learning with and constructing diverse and distributed information spaces. Future work could also more closely explore the use of peripheral elements of students' information spaces.

In this paper, we focused on making empirical contributions with rich descriptions for understanding the information practices of students in flipped classrooms, which will likely be of interest to members of the information and learning science community, especially those designing and evaluating educational technology. We found that students in flipped courses interact with a particularly heterogeneous collection of class materials and actively construct resources to aid their learning, including the creation of links, traces, information tapestries and social media back-channels. To better support students' learning, we must recognize their changing activity systems and adaptive information practices, and student agency in weaving the tapestry of their information spaces together.

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