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A Cluster-Based Approach to Understanding Students' Resource-Usage Patterns in an Active, Blended, and Collaborative Learning Environment*

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Data on how pedagogical innovations in engineering education impact the students' experiences and achievement are often lacking. The goal of this study was to identify and understand how and why students engaged with the resources available in an active, blended, and collaborative learning environment. We collected survey data from 581 engineering students on how frequently they used nine different resources of an undergraduate dynamics course. A cluster analysis identified nine, qualitatively-unique resource-usage patterns. We then analyzed 44 student interviews and found that students often exhibited their resource-usage patterns because of their perceived expectations and values for a given resource. The findings of this study provide instructors with data-driven information on the archetypical resource-usage and help-seeking behaviors of their students. Instructors can use this information to better coach their students and to design curricula and resources that support many different subgroups of students, not just the stereotypical or average student.

Keywords: cluster analysis; help seeking behavior; resource usage; engineering education

1. Introduction

Prominent reports have called for the adoption of engineering education innovations [1, 2], and active, blended, and collaborative learning are pedagogical strategies that continue to increase in popularity. Active learning involves physical activity [3], blended learning combines in-class instruction with online learning outside of the classroom [4], and collaborative learning incorporates students working in groups to attain a shared goal [5]. Studies have shown that active, blended, and collaborative pedagogies improve student learning [4, 6, 7]. However, in learning environments that enable the self-regulated use of blended resources for active and collaborative learning, it is often unclear how, and to what extent, students engage with the myriad resources available to them. Without having strong evidence for how students engage with the resources, instructors and course designers rely on assumptions, perceptions, and stereotypes for designing and improving educational resources and learning environments [8, 9]. This work aims to better understand how and why undergraduate engineering students engage with a variety of resources within a learning environment specifically designed to encourage active, blended, and collaborative learning.

According to Makara and Karabenick's [10] proposed expectancy-value model for resource selection, students choose their help sources based on four main factors: (1) the perceived availability of the source, (2) the perceived likelihood that the source will provide help if asked, (3) the alignment between the type of help provided by the source and the type of help desired, and (4) the perceived quality of the help from the source. Regarding the type of help desired in the third factor, researchers usually discuss two types of help-seeking behaviors (HSBs): adaptive and expedient [11]. A student's HSB is considered adaptive—also referred to as strategic or instrumental, but instrumental HSB should not be confused with instrumental motivation [12]—when the goal of the action is to understand the material and to become a more-autonomous learner in the future [13–16]. Conversely, expedient HSBs (also known as non-adaptive or executive) are characterized by a student seeking nonspecific help—e.g., when a student asks for help before they even try the problem—or help that leads to the correct completion of the task with as little effort as possible, which perpetuates their dependency on others to solve problems [11, 13]. The

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expectancy-value model proposes that students with shared help-seeking goals and similar perceptions of the expectations and values for the available help sources may choose to utilize similar help resources.

To date, researchers of academic HSBs have only considered the students' use of an individual resource, rather than as a part of an overall resource-usage pattern [e.g., 16, 17]. Multiple analyses of individual resources can provide information about the average use of a given *resource*, but they do not necessarily depict the holistic resource-usage behaviors of a given *student*. Resource-centered approaches provide little information about what *combinations* of resources were most prevalent or to what extent the students of a given resource-usage pattern shared common perceptions of the expectations and values of the resources they did or did not use. We posit that most students in technical courses, including engineering sciences courses, utilize a combination of help sources, rather than a single resource, and research has shown this to be true for students in the course of this study [18, 19]. Further, the course we study intentionally combines active, blended, and collaborative practices across a variety of aligned learning resources. Therefore, we contend that a student-centered approach is more appropriate than a resource-centered approach when trying to understand the holistic, archetypical resource-usage behaviors of multiple subgroups of students in technical, resource-rich courses.

Some researchers have recognized the value of grouping students together by common HSB characteristics [e.g., 13]. However, these researchers have grouped students according to their general help-seeking tendencies, which may not provide detailed enough results to inform the design or modification of a specific course's resources. Instead, this study exemplifies how researchers can group students according to their holistic usage behaviors of the specific resources that are available in a given course. Instructors can use this data-driven, resource-usage information—rather than assumptions or stereotypes—to better design and foster a learning environment that supports multiple, diverse subgroups of students [8, 9].

1.1 Purpose of study

This study aims to understand how and why students use the resources available in an undergraduate dynamics class (hereafter referred to as Dynamics, with a capital "D," whereas the field of dynamics will be referred to with a lower-case "d") taught within an active, blended, and collaborative learning environment called Freeform.

The following research questions (RQs) guide this work:

RQ1. When considering all of the resources of Dynamics simultaneously, what are the students' archetypical patterns of resource usage?

RQ2. How and why do students enact their respective resource-usage pattern, and to what extent do the students' perceived expectations and values for the resources influence their resource usage?

This work is part of a larger project researching the students' resource-usage patterns in Dynamics and the extent to which the students' patterns explain their performance in Dynamics. We focus on identifying and understanding the students' resource-usage patterns in this paper, and we investigate how the students' resource usage relates to their performance in Dynamics in a companion paper [20]. Knowledge of how and why the students use the available Dynamics resources coupled with their performance in the class could help instructors better coach students on how to be successful in the course, and it could guide the modification or development of resources to better support the students' learning [9].

A summary of each research question and their associated conceptual frameworks, analytical methods, and objectives is presented in Table 1. To our knowledge, this study is the first research on HSBs to employ a model-based clustering technique that groups students according to their self-reported usage data. After identifying the "clusters" (groups) of students who exhibit the same resource-usage pattern, we utilize student interviews to better understand how and why the students of each cluster used the resources as they did.

Table 1. An overview of the conceptual frameworks, analytical methods, and objectives associated with each research question of this study

RQ	Conceptual Framework	Analytical Method	Objective
RQ1	Expectancy-Value Model	Quantitative: Cluster analysis of students' survey responses indicating how often they use nine resources	To identify holistic, archetypical patterns of resource usage
RQ2	Expectancy-Value Model	Qualitative: Thematic analysis of student interviews	To understand how and why the students of each cluster used the resources as they did

We view our results through a conceptual framework based on Makara and Karabenick's [10] expectancy-value (EV) model for resource selection.

Giblin [21] also viewed their qualitative results through a framework based on Makara and Karabenick's EV model, and they found evidence that all of the EV factors, except one, influenced the resource selection of their upper-level-mathematics interviewees. It was unclear if the factor regarding the alignment of the type of help provided and the type of help desired influenced the students' source selection because all of Giblin's interviewees described their HSBs as adaptive in nature. This study uses a similar sample, engineering students, in a similarly technical course. Therefore, we expect to find evidence in the interviews that corroborates Makara and Karabenick's EV model of resource selection, but, if our interviewees also all describe their HSBs in the same way, we may not find evidence to support or refute the contention that the alignment of the help type affects the students' decisions.

1.2 Study context

In 2010, two engineering instructors implemented a new learning environment, called Freeform, for teaching Dynamics [22]. The Freeform learning environment was designed to align with the known benefits of active [7], blended [4], and collaborative [23] learning. The Dynamics instructors are encouraged to incorporate active and collaborative pedagogies in their classrooms, and an online discussion forum provides students with a way to asynchronously ask each other questions about the materials and their assignments. Freeform also includes a custom-written textbook, called a lecturebook, in which students write their notes and their solutions to example problems. Each section of the lecturebook begins with a short theory section and ends with the problem statements of many unsolved examples that have a problem-solving or conceptual focus. An online solution video accompanies every example problem in the lecturebook (excluding the conceptual problems) and every homework problem. Finally, the learning environment leverages a tutorial room that specifically supports statics and dynamics courses, and this "help room" is staffed by student teaching assistants (TAs) about 8–10 hours a day, six days a week. The distributed hours of the help room are essential because the Dynamics students have two homework problems due three times per week. Dynamics also has three intermediate exams and one final exam. The integrated suite of Dynamics resources is designed to accommodate a variety of help-seeking preferences as students prepare for, or complete, their assessments.

The general perceptions from Dynamics instructors and a limited amount of aggregated, course-level data suggest that students utilize certain Dynamics resources frequently (e.g., online videos) and others hardly at all (e.g., instructors' office hours) [19, 22]. However, the Dynamics resources are purposely designed to be aligned and integrated with one another, and the holistic patterns of resource usage that the students exhibit is unknown. Using a mixed-methods combination of cluster analysis, thematic analysis, and a conceptual framework based on an expectancy-value model for resource usage, this study seeks to understand the Dynamics students' resource-usage patterns to inform improvements to the Dynamics resources and to guide instructors on how to coach their students to be successful in the course [8, 9].

2. Conceptual framework

2.1 Importance of help-seeking behaviors

A student's help-seeking behaviors (HSBs) are commonly considered a strategy for self-regulated learning [15]. Pintrich and Zusho's [24] model of motivation and self-regulation posits that self-regulatory processes, like HSBs, can have direct and indirect effects on student's achievement. Resource-usage patterns are an outcome of the students' HSBs, so they too can relate to achievement. Thus, by better understanding their students' resource-usage behaviors, instructors further their insights into the factors that can influence their students' achievement.

2.2 Help seeking and self-regulated learning

The help-seeking process is considered a strategy for self-regulated learning (SRL) because it is a cyclical and reflective process in which students continually modify their behavior to better support their goal attainment [14, 16, 25]. The help-seeking process has been modeled as having eight components, see Fig. 1, and those eight components align with the three phases of Zimmerman's model for SRL [15]. This study focuses on the resource-usage outcomes of soliciting and obtaining help (Steps 6 and 7) and why students used the resources they did (Steps 4 and 5).

Because SRL is a cyclic and reflective process, a student's constant evaluation of the assistance they receive from specific resources (Step 8) could lead students to exhibit different resource-usage patterns depending on the type of help they desire (Step 4). A student with a mastery-goal orientation, reflecting the student's preference for understanding rather than simply getting the correct answer, could settle on the use of a different set of resources than a student who is performance-goal oriented and considers learning as secondary to completing the task

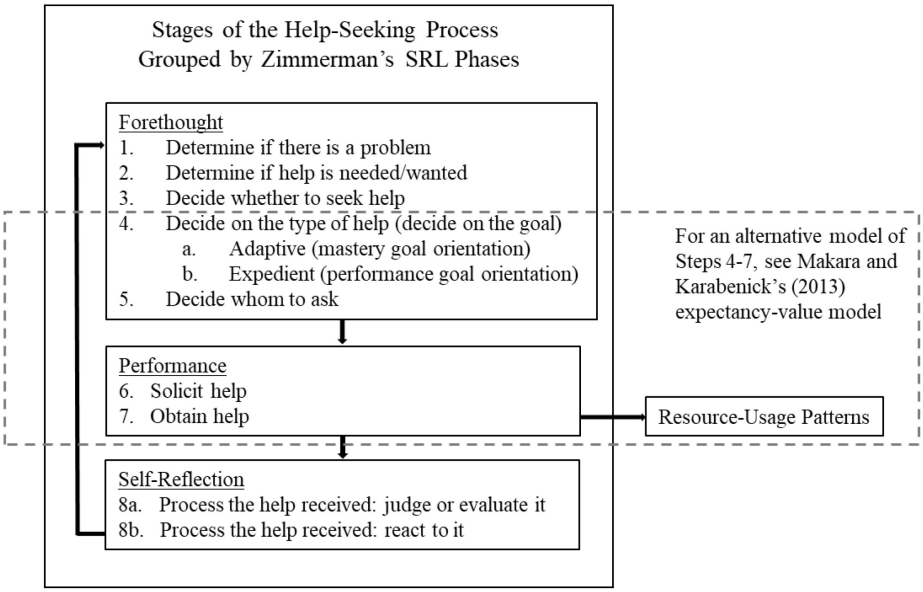

Fig. 1. A self-regulated-learning perspective of HSBs underpins the conceptual framework of this study. Figure based on [15], with annotations added by the authors.

correctly and quickly. However, there are other factors that influence a student's decision of what help source to consult, as elucidated by Makara and Karabenick's [10] expectancy-value model for resource selection.

2.3 Expectancy-value model for help source selection

Makara and Karabenick [10] proposed an alternative model for Steps 4–7 of the help-seeking process that is based on expectancy-value (EV) theory. The EV model, shown in Fig. 2, posits that the interaction of a student's expectations of a help source and the student's perceived value of the help source affect whether or not a student will seek help from that source. Makara and Karabenick proposed that the expectancy component of this model consisted of the student's perceptions of the accessibility and availability of the source and the student's perceived expectations regarding whether or not that the source will provide help if asked. Availability refers to whether a source could provide help, and accessibility refers to how easy that help can be obtained. The value aspect of this EV model clearly articulates that the type of help desired (adaptive or expedient) and the perceived quality and accuracy of the help directly influence which help source is chosen.

Overall, the EV model suggests that if a student perceives a source as being available and willing to help *and* the type of help the source provides is perceived as accurate and in alignment with the type of help they desire, then the likelihood of a student seeking help from the is source is high. Conversely, if the source is perceived to be unavailable, unwilling to help, misaligned with the type of help desired, or inaccurate, then the likelihood of the student seeking help from that source decreases. This EV model provides a framework through which we can view our quantitative and qualitative results to better understand which expectation and value factors contributed to the resource-usage patterns of specific subgroups of students.

2.4 Prior Dynamics results and the EV framework

Prior research that considered all of the students in Dynamics in aggregate, not grouped by resource-usage pattern, identified that the convenience and

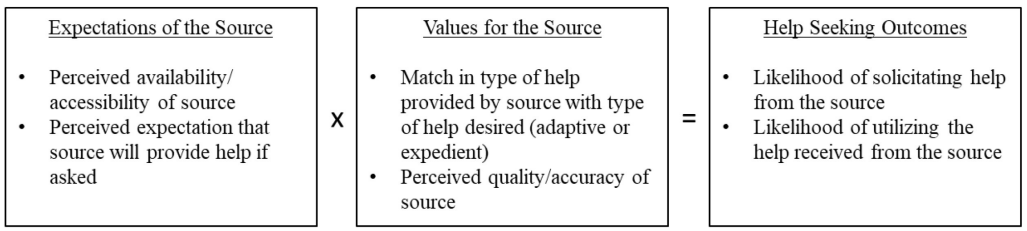

Fig. 2. An expectancy-value model for help source selection. Figure based on [10], with annotations added by authors.

availability of a resource [19] and the alignment of a specific resource with the task at hand [18] were primary determinants of what resources students used. These findings, when viewed through the EV framework, suggest that the perceived accessibility and availably of a resource along with its perceived quality had a significant impact on whether or not a Dynamics student used that resource. Overall, the previous research on the HSBs of Dynamics students contributed to our earlier hypothesis that we will find evidence that the factors in Makara and Karabenick's EV model influenced the Dynamics students' resource-usage decisions. However, we also acknowledge the possibility of not finding evidence that the help-alignment factor of the EV model influenced the students' resource-usage decisions because, like Giblin [21], all of the students in our sample may self-report their HSBs as adaptive in nature.

3. Methods

This study employed an embedded research design [26, Chapter 16] because quantitative and qualitative data that related to the same phenomenon, resource usage and HSBs, were collected from the students simultaneously, during the same semester. Furthermore, neither data source directly influenced the collection of the other, and the two data sources were collected to answer different research questions in this study. Quantitative survey data were used to identify clusters of students who exhibited the same resource-usage patterns (RQ1), and qualitative interviews provided insights into how and why students used the resources in certain ways (RQ2).

3.1 Participants

The data for this study were collected from students enrolled in Dynamics, a sophomore-level engineering course at a large, public university in the Midwestern USA with the highest category of research activity [27]. The sampling frame for this research was all of the students enrolled in the fall or spring semesters of Dynamics from Spring 2016–Spring 2018. Of the 1,379 students in the sampling frame, 581 voluntarily completed the survey that provided the quantitative data to investigate RQ1, and the interview transcripts of 44 students served as the qualitative data for RQ2. Additional details regarding our recruitment and sampling processes for the survey and interview data sources are included in the Appendix, and all data-collection instruments and procedures were approved by the university's institutional review board.

The demographic characteristics of all of the participants are shown in Table 2. This demographic data was obtained from the institution's Registrar, and the categories used in Table 2 reflect how the data were collected. Gender was reported by the institution as a binary variable, and we acknowledge that this is a simplification of the gender spectrum and that the terms "male" and "female" are terms to describe one's sex, not gender. We also recognize that race, ethnicity, and international status were all confounded together into one "ethnicity" variable. Nonetheless, the demographic characteristics in Table 2 help us better understand the backgrounds and socializations of the students in our sample.

3.2 Data sources

At the end of the semester, students were asked to

Table 2. Demographic characteristics of the survey and interview participants

	Survey Participants		Interview Participants	
Variable	**Count**	**%**	**Count**	**%**
Major				
Mechanical Engineering	459	79%	27	61%
Agricultural Engineering	32	6%	4	9%
Nuclear Engineering	28	5%	2	5%
Multidisciplinary Engineering	25	4%	5	11%
Other	37	6%	6	14%
Ethnicity (Race/Ethnicity/ International Status)				
Domestic, White	379	65%	30	68%
Domestic, Asian	31	5%	3	7%
Domestic, URM	25	4%	0	0%
Domestic, Other	34	6%	1	2%
International	112	19%	10	23%
Gender				
Male	437	75%	28	64%
Female	144	25%	16	36%

Note. The sum of the percentages for the ethnicity categories for the survey participants does not equal 100% because of numerical rounding.

Table 3. A description of the nine resources included on the end-of-semester survey and the median frequency with which students used the resource ($N = 581$)

Resource	Description	Median Frequency
My peers in the class	Group quizzes in class; virtual or in-person collaboration outside of class	1–2 times/wk
The course lecturebook	Combination of a workbook and concise textbook; students write notes and solve problems directly in book	3–6 times/wk
The lecture example and homework solution videos	Screencasts of the instructor solving a problem; every lecturebook example and homework problem has a solution video	1–2 times/wk
The course blog	"Blog" most often refers to the discussion forum, but could also be interpreted as the course website	1–2 times/wk
The instructor, by asking questions in class	Could include questions before, during, or after class	1–3 times/semester
The instructor, during office hours	Office hours were usually 1 hour long, 2–3 days/wk	Never
Online resources not accessed from the course blog (ex: online lectures or videos not associated with the course)	Could include online videos, online example problems, or online tutoring websites	1–3 times/semester
Other students I know who are not currently enrolled in the class	Friends who have taken Dynamics previously (although there is evidence in the student interviews that students may have misinterpreted this as asking about students in other sections of the course)	Never
The TAs in the Mechanics Tutorial Room	A dedicated help room staffed over 40 hours/wk with undergraduate- and graduate-student TAs	1–3 times/semester

complete a survey about their study habits, help-seeking behaviors, resource usage, and general experiences in the class. This study utilized one specific multiple-part question from the survey that asked the students to: "Please identify how frequently you use each of the following resources for help in Dynamics." The response options were (verbatim, and in the order in which they appear on the survey): at least once per day, 3–6 times per week, 1–2 times per week, 1–3 times per month, 1-3 times per semester, and never. The nine resources included in the survey question are listed in Table 3 along with their descriptions and their median response.

For RQ2, the students' resource-usage behaviors were explored through semi-structured interviews conducted with students during the last week of the semester in which they were enrolled in Dynamics. A predetermined set of questions probed a variety of topics including (but not limited to): the student's perceptions about the learning climate at the institution and in their major department, their preferred study strategies, their perceptions of the quantity and quality of the resources for Dynamics as compared to the resources provided for other engineering courses, their resource usage, and their recommendations to future students on how to be successful in Dynamics. The same set of questions was used for every interview, but the interviewer could reorder the questions and/or ask follow-up and clarification questions, as appropriate, based on the interviewee's responses. Because the interviews were limited to approximately 30–45 minutes yet were used to collect data for this study and several others, not all of the resources listed on the survey were explicitly discussed in the interview. For example, students were not directly asked about their use of other online resources not provided by the instructor or about their use of students not currently in Dynamics. The audio of each interview was recorded and subsequently transcribed by a third-party transcription service.

3.3 Data analysis

3.3.1 Quantitative analysis

To quantitatively identify the students' archetypical patterns of resource usage across all nine of the resources listed in Table 3, we conducted a model-based cluster analysis using the *mclust* package (version 5.3) in R (version 3.3.2) to evaluate 14 different clustering shapes with the number of clusters ranging from one to ten. The frequency-of-use data from the survey for the nine resources were on the same ordinal scale, so no data transformations were needed. Two of the primary advantages of model-based clustering over the commonly-used K-means clustering technique are that multiple shapes for the clusters are considered and the clusters can overlap because the classification of a student into a cluster is based on a vector of probabilities corresponding to the alignment of a student's behavior with that of the other students' behaviors in that cluster [28]. In contrast, K-means clustering separates students into exclusive groups that are spherically or circularly shaped [29]. Because we had no *a priori* knowledge about the shape of the resource-usage clusters and because we planned to use each student's vector of probabilities to gauge how well their behavior aligned with each

cluster's typical behavior, this study utilized model-based cluster analysis.

The selection of the best-fitting cluster model was primarily driven by the Bayesian information criterion (BIC), which is a likelihood criterion that penalizes models with increased complexity [30]. The shape and cluster-number combinations that had the three highest BIC values were considered the best-fitting models. The differences in the BIC values between the top three cluster models were small (less than 0.5% of a difference in the BIC values), so we compared the three models for differences in the number of qualitatively-unique patterns of resource usage. The most parsimonious model that also captured all of the qualitatively-unique usage patterns was selected as the final model.

3.3.2 Qualitative analysis

To better understand why students utilized the resources in certain ways, we conducted what Merriam [31] referred to as a basic qualitative study with the data from the student interviews. The focus of this basic qualitative study was to better understand the usage behavior that made each cluster qualitatively unique. The interviews of students within a given cluster were evaluated for common themes regarding why students in that cluster used a resource differently than many of their peers. We used a thematic-analysis process based on the guidelines of Braun and Clarke [32], as described in the Appendix. After the themes were developed, we viewed our results through the EV framework to determine which expectations or values for the resources were influencing the students' decisions on which resources they used.

Only interviewees with a cluster-classification uncertainty of less than 0.30 were included in the qualitative analysis because we wanted to understand the *archetypical* behaviors identified by the cluster analysis. A student's cluster-classification uncertainty is calculated as unity minus the maximum probability in the vector of cluster probabilities. The process of determining the threshold of 0.30 is further explained in the Appendix. Because this was an embedded research design where the survey and interview data were collected simultaneously, but independently, the number of interviewees in each cluster varied from one to 12, with the majority of clusters having 3 to 6 interviewees (see Fig. 3 for the distribution of interviewees across the clusters). Given the small number of interviews per cluster, we considered similar content across interviews to be a theme when it was mentioned by two or more students (for the clusters with more than one interviewee).

4. Results

4.1 Cluster analysis of survey data

4.1.1 Model selection

The cluster model that had the highest BIC (–16,490) had eight clusters, and the models with the second- and third-highest BIC values (–16,533 and –16,549) had nine and ten clusters, respectively. The model with nine clusters suggested that a group of students infrequently used the online blog (which, according to our interviews, students most often interpret as the discussion forum, but they could have also interpreted the "blog" to be the website as a whole), a usage behavior that was not reflected in the eight-cluster model. The ten-cluster model did not offer any additional, qualitatively-different usage behaviors compared to the nine-cluster model; the additional cluster was made up of students who asked the instructor slightly fewer questions and who used other online resources outside of those provided by the instructors a little more frequently than the students in an existing cluster of both the eight- and nine-cluster models. Given the ordinal scale on which students indicated their frequency of use of these resources, we did not believe the extra cluster of the ten-cluster model provided any more information about the students' resource-usage patterns than the nine-cluster model. Thus, the nine-cluster model was chosen as the most parsimonious model that still captured the qualitatively unique resource-usage patterns of the students. The average values for how frequently the students within each cluster used each of the nine resources of the survey are shown in Fig. 3.

In the nine-cluster model, the only two clusters that were substantially similar, C_2 and C_6, primarily used the same four resources, but students in C_2 used the other five resources slightly more often than the students in C_6. While one could argue that C_2 and C_6 did not exhibit qualitatively different resource-usage patterns, these two clusters were identified in models with seven, eight, and ten clusters also, so changing the number of clusters did not resolve the issue of having two similar clusters. We considered combining the similar clusters but decided to keep them separate in case the qualitative analysis yielded distinct differences between the clusters.

One measure of how well the cluster model fits the data is the uncertainty associated with the cluster classification of each student. For the nine-cluster model, almost half of the students had an uncertainty of less than 2%, and approximately 84% of the students had an uncertainty of less than 30% (which was the filtering threshold used for the qualitative study). These uncertainties were similar

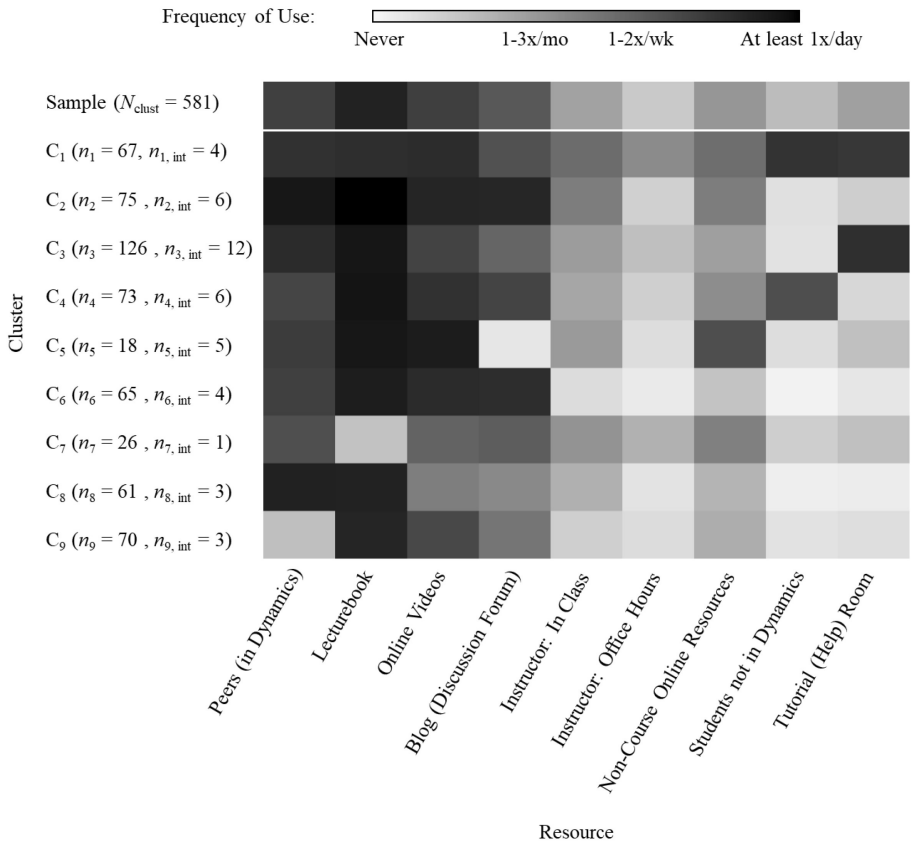

Fig. 3. The average values for how frequently the students within a cluster used each of the nine resources. The sample sizes with the "int" subscripts indicate the number of interviewees in each cluster (N_{int} = 44).

to those for the eight- and ten-cluster models, which had 85% and 83% of the students, respectively, with less than 30% uncertainty. The mean and median uncertainty for the nine-cluster model was 11% and 2%, respectively, which leads us to have high confidence in most of the students' cluster classification.

4.1.2 Characteristics of resource-usage patterns

Fig. 3 illustrates that a finite number of patterns represents the resource-usage behaviors of most students. Cluster 1 (C_1), on average, utilized the Dynamics resources the most often, and students in C_9 used the resources the least. This frequency of usage across clusters correlated with the students' survey responses regarding the time they spent on the class outside of lecture. For example, the number of hours per week that the students in C_1 (M = 10.34, Med = 9, SD = 5.23) spent on the class was statistically higher than the number of hours spent by students in C_6 (M = 7.8, Med = 7, SD = 3.0; U = 2862, p = 0.002, $r_{effectsize}$ = 0.273, small), C_8 (M = 7.0, Med = 6, SD = 3.5; U = 2955, $p < 0.001$, $r_{effectsize}$ = 0.387, medium), and C_9 (M = 7.2, Med = 6, SD = 3.4; U = 3285, $p < 0.001$, $r_{effectsize}$ = 0.349, medium), where U is the Mann Whitney U test statistic and $r_{effectsize}$ is the non-parametric, point-biserial correlation effect size that is categorized according to Cohen's suggested ranges [33, 34].

The students in every cluster consistently used at least two of the "core" resources of Dynamics, which we classify as peers, lecturebook, online videos, and the discussion forum. Thus, according to the EV model, these core resources must generally be perceived as available, willing to help, able to provide help that matches their desired type of help, and able to provide quality and accurate help. This logical inference aligns with the finding of Evenhouse et al. [19] when they qualitatively analyzed the HSBs of a similar, but aggregated, sample of students and found that the convenience and availability of the core resources contributed to their high usage.

The most common, holistic pattern of resource usage, that of C_3, mostly included the use of core resources and the tutorial room. The tutorial room is one of the few resources that has fixed times for its availability, so, according the EV model, its inclusion in the resource-usage pattern of the largest cluster likely indicates that many students perceived the value of the help it offered to be high.

As expected, the resource-usage patterns suggest that students did not use just one resource when

seeking help. With nine resources and nine clusters, it is conceivable that each of the clusters would be centered around the frequent use of a single resource. Instead, every cluster of students used multiple resources. This likely indicates an awareness of the different help sources for diverse needs. However, it also likely reflects some students' lack of SRL skills and an inability to match the help source to their needs, thereby causing them to consult multiple resources before getting the appropriate help. We revisit this issue of SRL skills in the qualitative analysis of the interview data from students in C_1 because students in C_1 used the most resources.

Almost every resource was frequently used by at least one cluster of students. The least utilized resources were those involving the instructor, which corroborates the findings of Wirtz et al. [35], who studied the HSBs of students in mechanical engineering at the same institution as our participants. Thus, the lack of using the instructor as a help source could reflect the departmental culture rather than the course-specific culture. It could also reflect the importance of instructors actively fostering an atmosphere of help seeking—which can be especially important in large classes [36]—that reduces the threat associated with hierarchical power relationships that some students perceive between instructors and students [11, 37, 38].

4.2 Thematic analysis of interview data

In this qualitative analysis, we focused on how and why students enacted their respective resource-usage pattern and how the students' perceived expectations and values for the resources influenced their resource usage. Therefore, we analyzed the student interviews for resource-usage themes within a cluster, rather than looking across clusters for themes regarding a specific resource, which has been done elsewhere [19]. We explain the resource-usage behaviors of students in C_1 for all nine of the resources; thus, the thematic analysis of C_1 is very thorough. For the other eight clusters, we briefly discuss the resource-usage characteristics that make that cluster unique. We highlight how each cluster's themes relate to three of the four factors of the EV model for resource selection: (1) perceived availability and accessibility, (2) perceived likelihood of the source providing help, and (3) perceived quality and accuracy. The one component of the EV model that we do not discuss until the end of this section is how well the help provided by the source matches the desired type of help (adaptive or expedient). We save this discussion until the end because all of the interviewees described their HSBs as adaptive, regardless of their resource-usage pattern. A summary of our key findings from the qualitative analysis is presented alongside the key findings of our quantitative analysis in Table 4.

Table 4. Summary of key findings from the quantitative and qualitative analyses

Cluster	Key Findings from the Quantitative Cluster Analysis	Key Findings from the Qualitative Thematic Analysis
C_1	Used many resources frequently; spent the most time on Dynamics outside of lectures; along with C_3, heavily utilized the tutorial room	Perceived culture as collaborative; generally perceived resources as available and willing to help; sought help from the TAs in the tutorial room after seeking help from other resources first
C_2	Similar to C_6; primarily relied on the core resources	The availability and accessibility of online resources reduced the need for TA help; scheduling conflicts hindered their ability to visit office hours
C_3	The most common usage pattern; primarily used the core resources and the tutorial room	Preferred the immediate, personalized, and accurate help of TAs in the tutorial room; organized their study schedules around the tutorial room hours
C_4	Often utilized the core resources and students not in Dynamics	Alignment of curriculum across sections enabled peers in other sections of the course to be a viable source of help
C_5	The smallest cluster; did not utilize the blog, but did utilize non-course online resources more often than their peers	Preferred private, group-messaging with a large group of peers over blog discussions; one student mentioned going to an online tutoring website if they were really confused
C_6	Similar to C_2; primarily relied on the core resources	Unlike C_2, did not use the instructor's office hours because of personal preference, not because of scheduling conflicts
C_7	Second-smallest cluster; used the lecturebook the least often; used many other resources moderately	Only one interviewee; purchased the book and later returned it because they perceived they could learn just as much without it
C_8	Primarily relied on their peers and the lecturebook for help	Read the theory portion of the lecturebook after class if confused; used online videos to assess their understanding; like C_5, preferred private communications with peers, but with a small group of friends and often in person
C_9	Infrequently used their peers; primarily relied on other core resources	Preferred to work and learn alone, enabled by the high availability and accessibility of online resources

4.2.1 Cluster 1 (frequent users of most resources)

The students in this cluster perceived the culture in engineering as collaborative, and they did not mind reaching out to their peers, TAs, or instructor for help with Dynamics. For example, one student commented:

> "[The undergraduate student culture is] good in the sense that a lot of people seem to want to help each other with understanding the concepts behind their classes. You know, I'll ask someone a question about a homework problem—and I can go up to practically anyone in the [mechanical engineering] building—and they'd be willing to help me through it." (Student 3)

Students in this cluster utilized many of the Dynamics resources when they did not understand a concept. The following quote illustrates the typical resource-usage behaviors in this cluster, all of which included some level of peer collaboration:

> "I do [the homework] myself first. If I don't get it, I'll look up [an] example [from the] lecture or lecture example videos online. And then, if I still don't get it, I'll go into the help room. And there's a lot of people [who can help you] there, too." (Student 1)

Multiple interviewees checked the online discussion forum for helpful hints, but they often did not find the forum that useful, in part because (in certain semesters) not many students were posting questions or answers:

> "I check [the discussion forum] while I'm doing homework sometimes, just to see if there's anything interesting or anything that I might be missing from this problem." (Student 1)

> "I felt like [the discussion forum] wasn't as useful because not many people seem to be using it. So, if you had a question it probably wouldn't get answered on the [discussion forum]." (Student 3)

One student, Student 2, mentioned that they utilized their friends who had already taken Dynamics, "I do study alone, but sometimes I have friends who already took their ME Dynamics before this semester, so I approach them and ask them questions."

Lastly, the instructor's office hours were used infrequently, but the students found the instructors' responses to questions in class helpful. For example, Student 2 said, "Sometimes, people don't understand, and the professor will give you extra information from that. That's one thing I like about the community, . . . they ask questions." Overall, the students in C_1 found the resources to be very helpful, as this student succinctly articulated:

> "If you're struggling, there are a lot of resources that you can go to. . .there are plenty of staff that you can get help from." (Student 1)

When considering the common behaviors of C_1 through the lens of the EV model, the students perceived many of the resources to be available and willing to provide help, but their perceived quality for the resources varied. The perceived quality and the likelihood of receiving help for the discussion forum was lower because the posted discussion *might* expose misconceptions and an asked question *may* be answered. The tutorial (or "help") room was referenced by multiple students as a place to go after first seeking help from other resources; thus, the students in C_1 appear to perceive the quality and accuracy of the TA's help in the tutorial room as being higher than the other resources, with the exception being the instructor. The interview data was inconclusive on whether the use of many resources is a sign of seeking deep understanding or the result of inefficiently aligning one's needs with the help source. Because these interviewees perceived the resources as being available and willing to provide help, it is possible that they move quickly from one resource to another if they do not immediately find the help they seek.

4.2.2 Cluster 2 (primarily core users)

Students in C_2 more frequently used the discussion forum while working on their homework when compared to C_1, possibly driven by their instructor encouraging their use of the discussion forum:

> "I used [the discussion forum] to do a quick check. . . [at] the beginning of the semester I used it a little bit more when [our instructor] was like, "Make sure you're using this." Then when [our instructor] wasn't saying, "Use it," I would just kind of forget about it." (Student 10)

As mentioned by Student 6 (below), the information on the discussion forum was not always useful to the students:

> "Towards the end of the semester, I checked [the discussion forum] probably every homework. . . . I thought it was useful just because different people brought up different things about the problems that I wouldn't think about. . . .But, then on the other hand, sometimes people would give answers that they wouldn't explain fully. So, it would be difficult to get what they were trying to tell you if they didn't explain it very well." (Student 6)

Thus, the students in C_2 perceived the discussion forum as more available and more likely to provide helpful insights than students in C_1, but the students in C_2 shared the same low perception of the discussion forum's quality and accuracy.

Compared to the students in C_1, the students in C_2 did not utilize the tutorial room or instructor office hours as often. Interviewees indicated that the availability and accessibility of various online resources reduced the need for students to seek help from the TAs, as exemplified by this quote:

> "I've been in the tutorial rooms but less [for Dynamics] because the online stuff is more available." (Student 10)

The difference in office hours use appeared to be primarily a result of scheduling conflicts that reflected the limited availability of the instructors' office hours. However, one student referenced the power differential, an aspect of accessibility, between the instructor and student as a cause for not asking the instructor questions:

> "I'm also like a bit intimidated by approaching him, and sometimes like I don't want to ask stupid questions. So, like for me, I would try to work by myself first, and if I really cannot understand, I would just go to help room or ask my peers because I don't want to appear stupid to the instructor." (Student 5)

Overall, the students in C_2 seemed to be heavily influenced by the availability and accessibility of the resources, but quality played a role in how likely the students would be to utilize the help, especially for the discussion forum.

4.2.3 Cluster 3 (core + tutorial room users)

This was the resource-usage pattern with the largest membership, and compared to most of their peers, the students in C_3 frequently used the tutorial room. They preferred the immediate, personalized, and accurate help that the tutorial room and its TAs provided to them. The tutorial room did have only certain hours of availability, but interviewees organized their study schedules around this availability so that the tutorial room was perceived as being highly available. For example, Students 11 and 17 took different approaches to solving their homework, but they both relied heavily on the TAs in the tutorial room for their learning:

> "I'll usually go home and try [to complete my homework] on my own at night. . . .And then, the next day, . . . I'll go to the tutorial room. . . .Most of the time, there's something that I've missed, or I haven't gotten, and then I'll go sit down at the table and solve it and try to fix my solution." (Student 11)
>
> "What I did that finally helped me understand [the course content] was immediately after class, I would just go to the help [tutorial] room. Just sit there; do homework where, if I needed help, I'd be able to ask the TA's there." (Student 17)

Multiple interviewees in this cluster acknowledged a tension between the expectations and value dimensions of the EV framework with regard to their peers, TAs, and instructors. For example, Student 12 said:

> "I think that the TAs in there are an even greater resource sometimes than the professor can be because they're more available. They're more available [than the professor] and more accurate [than your peers] then you're going to get the best of both worlds there. Maybe the [group messaging with your peers] might be more available, but not as accurate. And the professor, vice-versa." (Student 12)

Overall, the perceived high availability of the TAs in the help room coupled with a perception of receiving high quality help explains why students in this cluster utilized the help room frequently.

4.2.4 Cluster 4 (users of students not in Dynamics)

The interviews of students in this cluster did not reveal any insights into why students in this cluster utilized students not currently in Dynamics relatively frequently, but we did not explicitly ask for this information in the interviews. We did find evidence that suggests students in this cluster reached out to their peers in other sections for help (there were two sections of Dynamics each fall semester and four sections each spring semester), so students in this cluster could have misinterpreted the survey questions. The question regarding use of students outside Dynamics begins with the phrase "other students I know", and the first question asks about "my peers in the class." Thus, it is possible that students perceived the first question to be about students in their section and the subsequent question to be about students outside their section. The following is one example of how and why students worked with their peers from other sections of Dynamics and illustrates the value of aligning content across sections:

> "Sometimes if I didn't understand a general topic I'd also reach out to some of my peers who were in different sections to see, "Which examples did your professor do? Did they mention anything differently?" . . . The fact that [the course] was really organized, we were all on the same thing at the same time. I knew that I could study with others in different sections for exams and not be at a disadvantage." (Student 26)

For students in C_4, the alignment of the Dynamics curriculum across multiple sections increased the perceived quality of the help that peers in other sections could provide.

4.2.5 Cluster 5 (non-users of the discussion forum, users of non-dynamics resources)

Two factors that seemed to contribute to students in this cluster not using the discussion forum were their perceptions of the forum as having a low likelihood of providing help and low quality. In certain semesters, the usage of the discussion forum was quite low, leading some students to believe that the discussion forum *could* be a useful resource, but it was not for them. For example, one student said:

> "I don't think [the discussion forum is] super helpful now. I think it has the potential to be very helpful. Someone [who] took this [course] previously mentioned [that] when they took it the [discussion forum] was super, super popular. People were posting on it all the time and the only way to do the homework was to, like, look at the blog and see what people were posting. . . . But every time I checked, it was someone asking a question, [and] no one would answer it. . . .

> So, I think, again, it could be very, very helpful, but I don't think it was very helpful." (Student 33)

Interviewees in this cluster also did not use the discussion forum frequently because they perceived it as less helpful than other resources, indicating the value dimension of the EV model dominated their usage decision. Private communications with friends, often virtually via a group-messaging platform, were not viewable by the instructor and were perceived as being of higher quality than the public discussion forum because these private communications were more open and specific. The following quote illustrates this sentiment:

> "[When asking for help on the discussion forum], it's hard to know where the line is with cheating. . . . [Instead,] we have an environmental engineering Dynamics [group-messaging chat], and we'll usually ask a question like, 'Hey, this is what I'm doing. Does this look like what other people are doing?' Occasionally, people will post an answer like, 'I got this. Is this a close answer to what anyone else got?' . . . Again, hard to know where that academic integrity line is, but . . . [the group chat is] just not as public." (Student 32)

The students in C_5 were also more likely to find other online resources outside the Dynamics learning environment. These resources included content from an online tutoring platform—a platform that concerns the instructors because of how easy it is for students to receive expedient-oriented help. However, Student 31 described the website as just another support resource that they could use if they had exhausted their other options: ". . . if I'm really confused and stuck I'll go on [the tutoring website] and it'll sometimes help."

4.2.6 Cluster 6 (almost exclusively core users)

Students in C_6 displayed similar resource-usage behaviors as C_2, but, unlike students in C_2, who often did not use the instructor's office hours because of scheduling conflicts, the interviewees in C_6 simply preferred not to use office hours. When asked how often they received help from their instructor, these two students said:

> "Never. . . .That's just a result of me being me and not wanting to go to office hours, even though I probably should." (Student 37)

> "I personally don't interact with him that much. . . . I think if I needed to, he would be easily reached, and I can meet with him to talk about stuff, but I personally don't." (Student 38)

It is insightful to view the above comments through the lens of the EV model. Rather than the expectations and values for the Dynamics instructor determining whether or not the students in this cluster used the instructors' office hours, the students' prior help-seeking habits seem to have dictated their decision. This result aligns with Giblin's [21] proposition that students also use heuristics (or "empirically derived short cuts", p. 16) based on prior experience when deciding whether or not to seek help from a resource. Furthermore, portions of Student 38's quote, "I think if I needed to" and " I can meet with him", corroborate Briody et al.'s [39] findings that students use conditional statements and modal verbs (can/could/may/might) to justify and hedge their use of office hours.

4.2.7 Cluster 7 (non-users of lecturebook)

We had only one interview transcript to analyze for C_7; therefore, the archetypical behaviors of this cluster as exemplified by this one student are more tentative than the other clusters. The one student we interviewed in C_7 seemed to be budget conscious, meaning the price of the lecturebook limited its accessibility. They purchased the book, but did not use it, so they returned it. Instead, the student took detailed notes when the instructor used their own slides for explaining the theory of each topic. When the instructor solved an example problem, however, they did not take notes; they listened and tried to understand the process. They took notes on how to solve the example problems later, when they watched the online solutions for the lecturebook examples in preparation for doing their homework. Because they did not have the lecturebook as a reference, they clicked through many online solution videos until they found one (or more) that looked similar to the homework problem of interest. Overall, this student did not perceive their lack of using the lecturebook as a hindrance to their learning; they had this to say about the learning process they employed: "it's less expensive, and I feel like I learn just as much."

4.2.8 Cluster 8 (reliant on peers and lecturebook)

Students in this cluster primarily relied on their peers and lecturebook for support. All three of the interviewees exhibited similar usage behavior with the lecturebook, online videos, and their peers. They all read the theory portion of the lecturebook after the lecture to clarify the concepts, and one of the students also read it before the lecture. Overall, the interviewees found the lecturebook to be of very high value, as exemplified by this quote: "[At first] I didn't realize how helpful [the lecturebook] was and how directly it related to exactly what you're doing" (Student 35).

If working on their homework, the students in this cluster would only seek help from online example videos after they revisited the theory sections of the lecturebook. The students used the online homework and example videos to test their understanding before an exam, as illustrated by the following quote:

> "I kind of mentioned that I watch like half the lecture videos . . . before the homework, and then maybe I'll save them for before the exam. . . .Maybe I have a better chance to kind of refresh and go through new problems that I haven't seen before, right before the exam." (Student 35)

Like students in C_5, the students in this cluster appear to rely heavily on their peers for support through private channels rather than via the discussion forum. Two of the interviewees mentioned that help from people they knew and trusted was more useful than the information on the discussion forum, suggesting the quality aspect of the EV model drove their decision of who to ask for help. Unlike C_5, whose interviewees used a group-messaging platform to communicate with a larger number of students, the interviewees of C_8 kept their peer-network small. The interviewees often physically met with a small group of friends to do their homework, as described by Student 41: "If we are in a group, . . . we normally each do [the problem] on our own, and then stop at checkpoints, or when people get confused, and go over and make sure everyone is caught up." All of the interviewees checked their homework answers with their peers, either in person or via text messaging. The action of checking answers may appear to be performance-goal oriented, but these students described it as a way to get immediate feedback that they could use to correct misunderstandings. For example, one student said:

> "Most of my homeworks, I will either work together with my roommate, or check our answers together at the end. And that's really helpful 'cause a lot of times you can figure out that you were doing something wrong, and you may have just got your math wrong, or you may have a whole concept wrong, that you probably wouldn't have caught until the homework was already graded, and you were on to the next concept in class." (Student 34)

Overall, the high perceived quality, availability, and expectation to receive help when it was needed led the interviewees in C_8 to frequently utilize a small, intimate group of peers.

4.2.9 Cluster 9 (non-users of peers)

Most of the students in this cluster preferred to work and learn alone, which interviewees mentioned was enabled by the high availability and accessibility of the online resources. For example, one student commented:

> "I don't [interact with my peers] very often. I just like to work by myself. Especially with this class with all the resources there are online, it was easier to do that." (Student 42)

The interviewees in this cluster had varied reasons for not reaching out to their peers for help, ranging from not feeling a need for help very often to having poor experiences when they did ask for help, as Student 44 experienced:

> "I think I've tried [getting help from my peers] once, twice. . . . I found actually last year, when I tried to ask my peers for help, that everyone's like, "if you don't understand this by now, why are you here?" I've been told that a few times. I just quit [asking my peers for help]."

Like the quotes from C_6, the quote of Student 44 suggests that prior experiences influence current HSBs.

4.3 HSB orientations of each cluster

Our qualitative data suggest that the interviewees' HSBs were adaptive in nature across all of the resource-usage patterns and with respect to any individual resource. An example of an adaptive HSB, in the voice of the students, for each cluster is shown in Table 5. An example of how the students exhibited adaptive HSBs toward each of the nine resources considered on the survey is listed in Table 6. Evidence of all of the participants in a study exhibiting adaptive HSBs is not unprecedented; Giblin [21] noted that all 25 of their upper-level, undergraduate math students sought help for the purpose of understanding. Because of the lack of data regarding expedient behavior, we are unable to make conclusions about the relationship between expedient HSBs and resource-usage patterns. However, the evidence of adaptive HSBs across all of the clusters suggests that all of the resource-usage patterns can support students in their desire to *understand* the content.

The final notable finding from the qualitative research is in regard to the students avoiding the instructor as a help source. Some researchers classify this type of behavior as help avoidant, [10,13,39]. Earlier, we posited that the relative infrequency at which students use their instructor for help could be an indication of the hierarchical power differential between instructor and student. Our qualitative results suggest that students do not use the instructor as a help source for reasons that include scheduling conflicts with office hours and personal preference, but some interviewees mentioned intimidation or the fear of being perceived as "stupid" or "dumb" as reasons for not asking the instructor questions. One quote exemplifying this sentiment was included in the C_2 section above, and another quote follows:

> "I mean personally I would never go to the office hours. I would rather figure it out on my own, that's just because I feel intimated almost, to go to office hours because I don't know what's going on most of the time. I always kind of feel stupid afterwards because I'm talking to the instructor about how I don't know anything." (Student 33)

Table 5. Examples of adaptive HSBs for each cluster. The bolded text indicates key phrases related to adaptive HSBs

Cluster	Adaptive HSB Example
C_1	We have all the homework solution videos online, so every time, if I got something wrong, **I can go online to see what steps can I improve**. (Student 4)
C_2	I remember last semester I would go to help room a lot and, like, a few semesters before that too, because there is not other, like, electronic/online resources. But for [Dynamics], I could just **take time to solve the problems by myself and understand them.** . . . Usually I would just freak out by myself and just go to the help room and try to get the homework done without actually understanding [the problems], but this time I would just sit down and just try to study them. (Student 5)
C_3	I work on the problem in the Help Room, and, as soon as I get a question, I'm turning and I want an answer. Then and there while it's fresh in my mind and **I can really talk to the TA, not just about how to answer this question, but about the concept that's behind it and how I can learn from my mistake.** (Student 12)
C_4	I use my peers almost every day of the week for homework, studying, **clarification on concepts**, and they were my most useful resource. (Student 26)
C_5	Actually, several of us environmental juniors made a . . . group chat. That gives us a chance to go in and say, "Hey, I'm not understanding this. **Could you please help break down this concept?**" Or "Does anyone understand what he's asking in part D of such and such problem." That gives us a chance to go back and forth and bounce ideas off each other and figure out if there's, like, competing ideas or something, and work on that. (Student 30)
C_6	I'll copy down the homework assignments, and then I'll look through the lecture example videos to see if any lecture problems that we haven't covered are similar to it, and review those. **That way I get those ideas beforehand. Then I'll try the problem.** If I can't get through it on my own, then I'll check the various blog comments that people have left, and then pitch in if I can, and then go back and just finish up the problem. The next day, after turning it in, I think, is when they put up the solutions. I guess whenever the solutions go up, I'll go back and look and see what it is that I didn't do. (Student 36)
C_7	So, for the exams, . . . [once] I've learned as much as I can by reading and doing my own problems, but still making mistakes, **I learn the best by explaining it to someone. Because when I explain it to someone, ...I want to make sure I'm right in how I explain it**, so then I think I subconsciously pay extra attention. That's how I learn the best, I think. (Student 40)
C_8	I guess my strategy [for completing the homework] would usually be **to watch a couple of lecture examples and go through the textbook, . . . then I can just go straight into the homework.** . . . And then as far as working with other people, I'll usually go through all of [the homework] and make sure I think I have it right and then I'll just make sure that I have the same answers hopefully, and if I don't, then I'll have to go back and redo it. (Student 35)
C_9	My preferred method [of learning] is just to go through and continually do problems. A lot of times it seems repetitious or that you're not learning anything, **but every once in a while you run into something you didn't even think of or wouldn't think to look for and then you learn that way.** (Student 42)

Table 6. Examples of adaptive HSBs for each resource listed on the survey. The bolded text indicates key phrases related to adaptive HSBs

Resource	Adaptive HSB Example
My peers in the class	When I work with my friend, she thought of some concepts or ideas I have never thought [of] before. So, it's pretty useful to get me to understand the class materials better. And, like, **some of the homework I solve it differently, . . . but in the end I try to compare my answers with her is actually proof that, like, both concepts are right.** So, they help me to understand different ways of solving the problems. (Student 5, C_2)
The course lecturebook	I do notes in all my classes the week before for the lecture, **so I'll go through what the concept that we're learning is the next week and highlight things [in the lecturebook]**, and then we go over it in class. Then I'll use it for my homework then, and then I use it to study. (Student 41, C_8)
The lecture example and homework solution videos	Yeah, I use [the homework solution videos] all the time. . . . If I think I know what I'm doing **I'll go through and work the whole problem and then just skip to the end of the video to kind of see the solution and make sure I did the right thing.** (Student 31, C_5)
The course blog	. . . [when more students were using it], I thought [the discussion forum] was useful just **because different people brought up different things about the problems that I wouldn't think about**. (Student 6, C_2)
The instructor, by asking questions in class	I know my professor does a really good job of making sure that people actually ask questions and when they ask questions he doesn't say things like, . . . "oh well that's easy, you should understand this." **He'll actually answer them and understand that not everyone understands this right away.** (Student 44, C_9)
The instructor, during office hours	My instructor, I utilized . . . several times throughout the semester for office hours . . . **for special clarifications on concepts** . . .. "That didn't click the first time. **Can you explain it to me a different way?**" Or, I'd go to a different professor's office hours to see if they explained it in a way that was better for me. (Student 26, C_4)
Online resources not accessed from the course blog (ex: online lectures or videos not associated with the course)	I do Google a whole lot of stuff. [An online tutoring website] is pretty helpful, and . . . a lot of times you'll find the exact problem on [the website], but they're not that useful because the guys on [the website] get it wrong all the time. **But just to see their thought process is quite helpful.** (Student 40, C_7)
Other students I know who are not currently enrolled in the class	I do study alone, but sometimes I have friends who already took [Dynamics] before this semester, so I approach them and ask them questions . . . If they still have **resources from their semesters so that I can use it and study** or just ask them for help or something. (Student 2, C_1)
The TAs in the mechanics tutorial room	So, I utilize the help room quite a bit, which there's a TA in there, but there's also other students in Dynamics who are working on the same problems. . . . **I usually talk to the TA first about problems, and then once I have a good understanding of it**, if [there are] any students in that room, and there's a line for the TA**, I'll try to explain that to them** because I find I learn better when I'm explaining things. (Student 14, C_3)

These quotes highlight the need for instructors to actively cultivate a culture of help seeking that encourages students to ask questions and reduces their fears of "looking stupid" if they need help [11, 39].

5. Discussion

The aim of this study was to identify (RQ1) and understand (RQ2) the holistic patterns of resource usage by students in a resource-rich, blended learning environment for an undergraduate dynamics course. The summaries and implications of our results are organized below by research question.

5.1 RQ1: patterns of resource usage

The most important result from the cluster analysis of the students' self-reported resource-usage data (see Table 3) was that there is not one typical resource-usage pattern for students in Dynamics; our analysis identified nine common resource-usage patterns. So, when instructors evaluate how well the Dynamics curriculum and Freeform environment supports the learning needs of all students, they should consider at least nine archetypical students, not one stereotypical student.

The identification of nine archetypical resource-usage patterns illustrates that students are tailoring their use of resources to their preferences, needs, and schedules—yet, a finite number of patterns captures how most students use the resources. The finding that all of the students are referencing multiple help sources of diverse types (face-to-face, mediated, text, video, etc.) reflects the integrated nature of the active, blended, collaborative resources of the Dynamics learning environment. When viewed through the EV framework, the fact that each of the nine resources was frequently used by at least one group of students indicates that every resource is perceived as available and valuable to at least some students, and instructors, therefore, should continue to offer the current suite of Dynamics resources in future semesters. At the same time, instructors should consider altering the resources that are less frequently used—e.g., instructor office hours—to better support more students.

The frequent use of the tutorial room by students in C_3 (the cluster with the largest membership) and C_1 indicates that access to a TA is a valued component for many students in the suite of Dynamics resources. In addition to receiving help, some students who used the tutorial room may have honed their SRL skills and enacted adaptive HSBs because, ideally, the TAs encouraged SRL and mastery-goal orientation [40]. Student interviews suggested that some students used the tutorial room because it provided them with a more informal and less-intimidating path to expert help than visiting an instructor's office hours. Unfortunately, tutorial rooms open to all students and for specific courses are not a common resource for most universities. This study's institution makes helping students in the tutorial room the sole responsibility of the course's TAs. Because Dynamics has multiple sections and TAs are expected to work 20 hours each week, multiple TAs are hired each semester to provide 40+ hours of tutorial-room availability each week. Each instructor also hires one undergraduate student to help them grade the homework assignments. This sharing of resources across sections and the specialization of job functions allows this study's institution to offer the tutorial room, and we hope our findings encourage more engineering departments to consider providing this type of resource.

Lastly, the students' high perceptions for the expectations *and* value of the core resources was evident in the high usage frequencies for those resources. Other resources that were perceived high on only one of the dimensions of the EV framework were not used as universally. For example, non-course online resources were always available (although one could argue not as accessible because a student has to search for relevant content), but some interviewees suggested that they could be lacking in quality and accuracy. Similarly, students perceived instructors and TAs as sources of very high-quality help, but these resources were not as available or accessible as the core resources (with a possible exception being the discussion forum in semesters with low participation). In summary, our results corroborate the EV framework of Makara and Karabenick [10] and the findings of Evenhouse et al. [19] and Wirtz et al. [35] in that the availability, convenience, and quality of a resource are important factors in determining if a student will use the resource.

5.2 RQ2: understanding how and why

The qualitative interviews revealed a wide variety of reasons that students engaged with the resources as they did. One of the more common themes of how students utilized the Dynamics resources was to work on an assignment alone and only seek assistance if they could not overcome the challenge by themselves. The order and frequency in which they used a resource for help varied by cluster and depended on the students' perceptions of the expectations and value for each resource, as suggested by the EV model for resource selection, with the students' perceptions being influenced by their own schedule, needs, and preferences.

Overall, the results of the qualitative analysis corroborated three of the four expectation and

value factors listed in Makara and Karabenick's EV model, see Fig. 2. The one factor of the EV model that our interviewees never seemed to consider when choosing a resource was how well the help provided would match the type of help (adaptive or expedient) desired. However, all our interviewees described their HSBs as adaptive, so our results do not contradict the EV model, but they do not confirm the EV model either.

5.3 Implications for practice

The cluster analysis used to group students according to how they use a set of resources is generalizable to any resource-rich learning environment. The only data required are responses to one multiple-part survey question. Thus, any instructor could employ the quantitative portion of our research design to identify how their students use the resources available to them. This information could be used to make decisions about how an instructor or department allocates their time or money to best support the learning needs of their students. For example, if administrators only looked at the average usage of each Dynamics resource (the top row of Fig. 3), they may conclude that the tutorial room is used relatively infrequently compared to other lower-cost resources (like the discussion forum or the online videos). Consequently, they may decide to discontinue offering TA support in the tutorial room, or significantly cut back on staffing hours. However, the cluster analysis reveals that the students in two of the nine clusters (approximately 33% of the total sample) frequently used the tutorial room, and one of those clusters had the largest membership. Thus, analyzing the behaviors of subsets of students, rather than analyzing the average behaviors of the sample, can have a practical impact on how instructors and administrators spend their time and financial resources to support students.

Because our results suggest that all of the resources can be used in adaptive ways, instructors may want to limit the time spent advising students on the specific resources they should use. Within the scope of coaching students on resource usage, instructors could reiterate the variety of resources available and emphasize the importance of the self-evaluation phase of SRL (Step 8 in Fig. 1). One concrete example of how instructors could help students develop their metacognitive awareness and self-regulation is to implement a "post-test analysis," which includes multiple reflection exercises [41], but there are many alternative pedagogical ideas for improving students' SRL skills in the research literature [e.g., 42–45]. Based on Karabenick and Berger's [15] representation of help-seeking as a SRL process, as shown in Fig. 1, the better students get at critically evaluating the usefulness of the help they receive, the better they should get at matching their needs to a help source. The development of SRL and help-source-matching skills would benefit all of the students, but it could be especially valuable for some of the students in C_1 if lower SRL skills is the cause of the students in C_1 spending the most time, on average, on Dynamics outside of class and using the most resources of any of the clusters.

Another actionable finding from this work is for the instructors to consider alternatives or modifications to the online discussion forum. The cluster analysis indicates that many students use the discussion forum, but a considerable number of interviewees described it as an unreliable source of support (in terms of accuracy and expected response). Students often preferred to rely on small, private, and personal peer networks for help. Therefore, instructors should evaluate if there is a way to preserve the valued aspects of the private, smaller-group communications while also making that information available to all of the students in the class. Alternatively, Er and Orey [11] suggested that instructor participation on the discussion forum or adding a social-networking aspect (like following, friending, or liking) could encourage participation and reduce the fear of seeking help publicly. Regardless of what modifications are considered, the asynchronous nature of the discussion forum may still cause some students to perceive it as less useful. Students who work on their homework right after it is assigned may not find the discussion forum as useful because the posted content and student participation are more limited than they are in the hours leading up to the due date [19]. Nonetheless, any improvement to the content or participation on the discussion forum will likely differentially benefit those who do not have the affordances of being part of a smaller network of peers, thereby improving Freeform's ability to support the success of *all* students.

5.4 Implications for research

This study suggests that most students seek help from multiple resources, and how and why the students choose to use certain resources varies across the resource-usage patterns. We posit that the use of multiple resources is not unique to Dynamics and is true in most undergraduate courses, especially in engineering where students often have at least a textbook (or course notes), their peers, internet resources, and the instructor's office hours available to them [35]. A holistic, student-centered approach allows researchers to identify and understand the multifaceted resource-usage characteristics of smaller subgroups of students, whereas the investigation of individual resources in isolation primarily reveals the aver-

age-usage statistics for each resource without contextualizing those statistics in the broader help-seeking behaviors of specific students. Therefore, to accurately understand how and why students use the resources available to them, researchers should employ a holistic, student-centered approach instead of a resource-centered approach.

5.5 Limitations and future work

One of the most significant limitations of this work is the limited sample sizes of both our quantitative and qualitative data. Because the cluster analysis suggests that nine patterns describe the resources-usage patterns of most students, the number of participants (survey and interview) that we had in each cluster became limited. Future research that conducts targeted sampling of interview participants from less-common clusters would allow for a more thorough investigation into why students in those clusters engage with the resources as they do.

A second limitation of this work is that both the quantitative and qualitative analyses relied on self-reported data. For the cluster analysis, self-report errors in the resource-usage responses on the survey could have affected the students' cluster classification. We expect, however, that errors in the survey data had a minimal effect on most of the students' cluster classification because: (i) the classification uncertainty for most students was very low, meaning that the resource-usage pattern of most students only aligned with that of a single cluster; (ii) the nine resource-usage patterns were qualitatively unique, so gross misrepresentations of a student's resource usage would have been necessary for a student to be misclassified; and (iii) the thematic analysis of interview transcripts for students within each cluster corroborated the quantitative resource-usage patterns. Regarding the qualitative data, it is possible that the interviewees did not feel comfortable sharing details of how or why they used certain resources. Some interviewees may have misrepresented their behavior because of fear for how the interviewer may perceive them [46]. We tried to minimize this impression threat by conducting the interviews in a location that was not connected with Dynamics and by utilizing an interviewer who was not associated with the instructional team for Dynamics. Nonetheless, the possibility that students misrepresented their resources-usage behaviors in the interviews could have contributed to our lack of evidence regarding whether or not students enacted expedient HSBs.

In future studies, our data collection instruments and processes could be improved and aligned. The end-of-semester survey should clarify its language regarding the "blog" and students who are not currently in Dynamics. Through our interviews with students, we have found that the majority of students perceived the "blog" to be the discussion forum, but some students considered the course blog to be the course website (as a whole). In the interviews, we should explicitly ask students about their tendencies to use online resources outside of the course and peers not currently in Dynamics. We should also consider ways in which we can better research the extent to which students in each cluster exhibit expedient HSBs. One option is to consider administering a HSB instrument [e.g., see 13] to get a sense of the students' general HSB tendencies.

Finally, future work (which is presented in a companion paper [20]) needs to correlate the students' resource-usage patterns to their achievement in Dynamics. The results of this study suggest that the students in all clusters sought to develop an *understanding* of dynamics. If the students across all clusters were equally successful at developing this understanding, then we would expect the performance of the students in each cluster to be similar, and a student's resource-usage pattern would not be a significant predictor of their achievement. An insignificant relationship between a student's resource-usage pattern and their achievement would also further strengthen the possibility that the specific resource (or usage pattern) from which a student seeks help should not be the focus of academic coaching because students can engage with the resources in many different ways and still achieve similar academic results. Alternatively, if a student's resource-usage pattern is a significant predictor of achievement, then the proposed future work could inform the coaching of students on what resource-usage patterns might maximize their academic achievement in Dynamics.

6. Conclusion

As engineering education continues to adopt and develop innovative teaching methods and learning environments, researchers must investigate how students experience these innovations and how the innovations affect the students' learning. The purpose of this research was to better understand how and why students utilized the plethora of resources that were available for an undergraduate engineering course that emphasized active, blended, and collaborative learning. We identified nine qualitatively-unique patterns of resource usage, indicating that students regularly consulted multiple resources in the highly-integrated environment. Interviews suggested that the students exhibited their respective resource-usage patterns according to three out of the four factors in Makara and Karabenick's [10] expectancy-value model for resource selection. Our interviewees described their HSBs as adaptive

regardless of their resource-usage pattern; therefore, we found no evidence to support or refute the fourth factor of the expectancy-value model which contends that students will choose a help source that provides the same type of help (adaptive or expedient) that is desired. Overall, our results reflect the value of having multiple, highly-integrated resources to support students' unique needs, preferences, and adaptive HSBs. With this increased understanding of how and why students utilize the resources, instructors no longer have to rely on anecdotal evidence, assumptions, or stereotypes and can instead evaluate curricular and resource changes with regard to how the changes may affect the students of each data-driven, archetypical resource-usage pattern.

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Appendix. Additional Method Details

Participants

Approximately 500 students enrolled in Dynamics each year, with the most students (over 350) enrolling during the spring semester. The total number of survey responses was 581, comprised of 95, 36, 139, 83, and 228 responses from the Spring 2016, Fall 2016, Spring 2017, Fall 2017, and Spring 2018 semesters, respectively. From Spring 2016–Spring 2017, no incentive was given for completing the survey. For the Fall 2017 and Spring 2018 semesters, additional questions from a partner organization were appended to the original survey, and ten points of extra credit toward the student's homework grade (which amounted to less than 0.45% of extra credit toward a student's overall grade in Dynamics) were given to anyone who completed the survey.

Regarding the qualitative data, students were offered a $20 gift card for participating in an interview. Participants were recruited through email, using a stratified sampling strategy based on prior GPA, section (instructor), and international status to capture the experiences of different student groups. These stratifications reflect the fact that the student interviews were used to collect data for this study and many others not discussed here (e.g., how the students' experiences in Dynamics differed across instructors with varying levels of experience teaching the course). Regarding the international-status stratification, we expected that a student's experiences in the class may vary more according to a student's international status than according to their gender or major because of language and cultural differences.

Our goal was to interview at least two students from each of the stratified student groups. If the number of participants was low in a given stratified group, then up to two follow-up recruitment emails were sent to that group. Over-participation from a stratified group was allowed as no volunteer was denied an interview.

A total of 53 interviews with students who also completed the end-of-semester survey were completed between Spring 2016–Fall 2017 (there were none conducted during Spring 2018), but this study only utilized 44 of those interviews. We used a subsample of the interviews because we wanted to better understand the archetypical resource-usage behaviors of the students. Therefore, if a student's usage pattern did not meet a threshold for alignment with one of the most-common patterns of resource usage, as further explained in the Data Analysis section, the student's interview data was not used in the qualitative analysis.

Data Analysis

Interviewee Selection

The cluster analysis results were used to subsample the student interviewees so that we only analyzed the interview transcripts of students who exhibited resource-usage behavior that aligned well with one of the archetypical resource-usage patterns. We used a measure of cluster-membership uncertainty to do this, which

is calculated as unity minus the largest cluster-membership probability—see the Data Analysis section of the main paper for more details. The qualitative analysis only included students with cluster-membership uncertainties of less than 0.30. When considering the entire sample, approximately 84% of the students had an uncertainty less than 0.30 (the mean uncertainty was 0.11, and the median was 0.02). We also considered a lower uncertainty threshold of 0.10 (~68% of the sample had an uncertainty of less than 0.10), but the number of students who completed an interview and had uncertainties less than 0.90 was ten students fewer than a threshold of 0.30. Of these ten students, five were women and four were not mechanical-engineering majors; all were domestic students. Given that the cluster analysis is largely driven by the patterns of resource-usage of the majority—White, domestic men majoring in mechanical engineering—we decided to use the higher uncertainty threshold of 0.30 in order to improve the diversity of the interviews included in the qualitative analysis.

Qualitative analysis

We used thematic analysis to find themes from the students' interview transcripts in their descriptions and explanations of their resource-usage. We used a thematic-analysis process based on the recommendations of Braun and Clarke [32]. The coding happened in two phases. First, to categorize the content of the interview, we read through each interview and coded the content related to each of the resources listed in Table 1 of the main paper. For this categorization of content, we used a coding scheme developed by Kandakatla, et al. [18]. This coding was completed mostly by one undergraduate research assistant, and two inter-rater reliability checks with one of the authors ensured coding consistency. Then, for the second phase of coding, we reread the transcripts and then, using the codes from the first phase, extracted the resource-related content that corresponded to the unique resource-usage characteristics of each cluster. This extracted content for students in a given cluster was coded for interesting features. These initial codes were then grouped according to potential themes, and the transcripts were reread to ensure that these potential themes accurately represented the students' thoughts and words. The final themes were summarized for each cluster. Lastly, the themes were viewed through the expectancy-value conceptual framework for resource selection to determine what factors of the expectancy-value model seemed to influence the resource usage of the students in each cluster.

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