Time-Turner: A Bichronous Learning Environment to Support Positive In-class Multitasking of Online Learners

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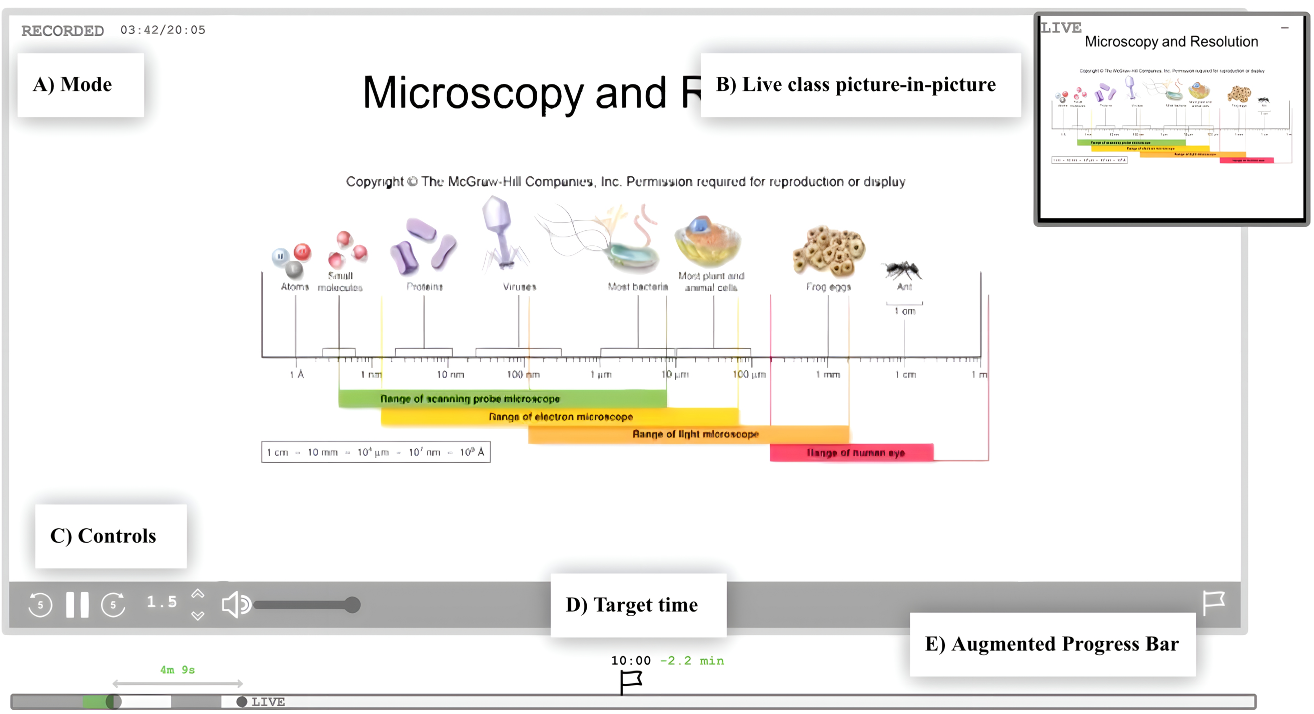

Figure 1: An overview of the cognitive design elements prototyped in Time-Turner. A) The mode label shows Recorded/Live when students are watching the past/real-time content respectively. B) In the recorded mode, the live class is shown in picture-in-picture view to let students be aware of the events in the live class if needed. C) A set of controls (pause, skip back, skip forward, change playback speed) is provided. D) Students are able to set a target time for when they need to be caught up to the live class. E) An augmented progress bar provides temporal information to students about the watched/missed content, and their location relative to the live class.

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ABSTRACT

University students engage in a substantial amount of multitasking in online classes despite being aware of its negative impacts on their learning. Depending on the learner's goals, in-class multitasking can be a positive strategic behavior to increase productivity. In a formative pilot study (N=10), we established the structure and scope for our design by exploring students' motivations, perceptions, and challenges in in-class multitasking and identified several promising design elements. Our design facilitates multitasking in online synchronous classes by providing a novel bichronous (blending of synchronous and asynchronous) learning environment manifested in *Time-Turner* that enables asynchronous guided accelerated viewing of past content during synchronous classes. A summative evaluation of our prototype showed significant improvement in learning outcomes when multitasking (N=20). Furthermore, 95% of users found *Time-Turner* helpful and expressed interest in having it in their online classes. Our findings show the great potential of supporting positive multitasking in synchronous online classes.

CCS CONCEPTS

• **Human-centered computing** → *User interface design*; *Interface design prototyping*.

KEYWORDS

in-class multitasking, bichronous learning, online learning interfaces

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1 INTRODUCTION

Multitasking is defined as interleaving multiple tasks at the same time frame and switching between them [1]. Improving efficiency is one of the main motivations behind adopting multitasking in day-to-day activities [17]. Therefore, multitasking is an extremely common practice among university students who struggle to tackle their high workloads and time constraints. Depending on which goals are used as a reference and which consequences are analyzed, multitasking can be considered a strategic behavior that benefits learners in the big picture [38]. However, while many students engage in in-class multitasking aiming to increase their productivity, it does not come without its own disadvantages. There is a large body of research demonstrating the negative effects of in-class multitasking on students' learning outcomes and performance [7, 12, 24, 26]. Even though the potential consequences of multitasking are recognized by most students [33], research shows that university students engage in a notable amount of multitasking when attending their classes [19], and even significantly more in online classes compared to traditional in-person classes [2, 27]. The advantages of online *synchronous* learning in increasing satisfaction and self-evaluated performance of students by enabling social presence and providing opportunities for interaction and feedback [13, 43], make it a key part of modern online education. This motivates us to further explore students' multitasking in online synchronous classes and design solutions to improve their learning experience.

To establish the structure and the scope of our design and to identify requirements, we conducted a formative pilot study (N=10) where we asked university students to keep multitasking diaries in 2 or 3 sessions of their online synchronous classes, and followed up with semi-structured interviews to dive deeper into students motivations and perceptions of in-class multitasking and their possible challenges. We found that when reflecting back on their in-class multitasking activities, our participants were mostly satisfied with their choice to multitask in class and believed the benefits of their multitasking outweighed its detriments. A common theme observed in our exploration was that participants chose to multitask in their classes when they found their secondary task of high importance and/or found the learning task of low importance. Finally, we organized the main observed challenges of in-class multitasking into cognitive and metacognitive consequences for learning. Based on the insights gained from our formative pilot study, we seek solutions that support in-class multitasking instead of eliminating it, by addressing its potential consequences for students' learning outcomes.

To address the cognitive consequences of in-class multitasking we elicit our first requirement *R1. Enable immediate recovery of missed content in the class time frame.* To satisfy R1, we propose a bichronous learning [1][32] environment that enables accelerated guided viewing of past content asynchronously in online synchronous classes immediately after multitasking to prevent the content loss, context loss, and the need for extra time spent on the lecture content asynchronously. In an experimental evaluative user study (N=20) we evaluated the proposed cognitive design elements implemented in a prototype called *Time-Turner*. Our results show that compared to a baseline system, Time-Turner shows significant improvement in students' learning outcomes when they multitask during a simulated online synchronous class. Qualitative feedback from our participants showed high levels of interest in gaining access to these design elements in online synchronous classes.

To address the metacognitive consequences of in-class multitasking, we elicit our second requirement, *R2. Provide assistance in metacognitive monitoring in in-class multitasking by enabling cognitive offloading.* To satisfy R2, we propose time, topic, and activity-based cognitive offloading that assist with metacognitive monitoring when multitasking. Integrating lecture slides with the live class provides topic sections that can be used as bookmarks. Interactive components of the lecture such as discussions and Q&As are also presented as sensitive events that can trigger an alert and bring students back to the live class. Finally, time-based cognitive offloading allows students to plan their multitasking and receive aid in regulating their actions accordingly. Our qualitative evaluation of the proposed metacognitive design elements shows their effectiveness in common scenarios.

In this work, we contribute (i) empirically established design elements that support positive multitasking by effectively mitigating its adverse effects on students' learning outcomes, and (ii) new empirical insights on students' perceptions of in-class multitasking and a categorization of their challenges which provides structure and scope for our design process.

2 BACKGROUND AND RELATED WORK

In this section, we explore the related work in three different parts. First, we highlight the prevalence of in-class multitasking and its

[1] A blending of synchronous and asynchronous learning [32]

observed effects on learning. Second, we bring evidence that multitasking can be a conscious choice to increase productivity. Lastly, we review existing designs for multitasking.

2.1 In-class Multitasking

In the context of learning, multitasking can be defined as dividing attention between two or more tasks and performing non-sequential task switching in a learning situation [20]. In this paper, we focus on in-class multitasking in online synchronous classes which limits the learning situation to an online lecture or class.

Studies show that students engage in a significant amount of in-class multitasking. Using a combination of observation and surveys among 3000 students, Ragan et al. [39] found that students engage in off-task computer activities in the class almost two-thirds of the time. In another study by Fried [14], in-class laptop users reported multitasking for 17 out of 75 minutes of the class. Of those students 81% reported that they checked email during the lectures, 68% reported that they used instant messaging, 43% reported surfing the net, 25% reported playing games, and 35% reported doing "other" activities.

While prevalent, the negative impacts on students' learning and academic performance are clear. A study by Kuznekoff et al. [24] found a significant difference in learning between the control and high-distraction groups with the students in the control group writing down 62% more information in their notes and scoring 1.5 letter grades higher. In a similar study Macdonald [34] identified that there is a negative correlation between students' in-class texting and their final grade and GPA. In a study by Conard et al. [9], interrupting students with text messages in the class led to a significant margin in learning that was affected, but not fully moderated, by the student's interest in the topic.

Laptop multitasking has similarly been researched and shown to be reducing students' learning outcomes. Hembrooke et al. [16] shows that laptop use reduces students' recall and recognition scores on the lecture content. When it comes to online classes specifically, research shows that students engage in a significantly larger amount of multitasking in online classes compared to in-person classes [27].

Elder [11] found that students believe that cellphone use in college classes interferes with their learning and concentration. However, these beliefs do not prevent them from multitasking. Another study shows that students were able to accurately predict their decline in learning in in-class texting conditions compared to non-texting conditions [15]. This further confirms that students are aware of how their in-class multitasking affects their academic outcomes to an extent. This raises the question: Why do students choose to multitask in class despite being aware of its negative consequences?

2.2 Positive/productive multitasking

Szumowska et al. [41] research the origins and motivations behind multitasking. In their experiments, they show that the frequency of multitasking correlates with the number of active goals that people pursue. They also demonstrate how the relative importance of goals makes a difference in multitasking where the degree of multitasking decreased in a condition with one goal being significantly more important than other goals compared to all goals being equally important. To confirm their results, they experimented in a learning setting with 138 university students and measured their mobile in-class multitasking and the relative importance of the learning goal and showed that the greater the importance of the learning goal, the less students engaged in mobile multitasking.

It is worthwhile to consider that depending on the student's active goals and their importance, in-class multitasking can be beneficial to them overall. Poplawska et al. [38] suggest that many people use media multitasking in educational or occupational domains to satisfy their professional, social, and emotional goals. Depending on what goals we use as reference and what consequences we analyze, media multitasking can be viewed as a beneficial strategic behavior to achieve goals or a shortcoming in self-regulation. Even though the existing research on multitasking in the domain of education is mostly pointing toward its effects on reducing performance, some studies show the potential benefits of multitasking in online workplace meetings. Cao et al. [8] perform a large-scale analysis of multitasking in remote online meetings. They suggest that multitasking in online meetings can lead to a boost in productivity.

While there is no doubt that in-class multitasking impairs students learning and academic performance, taking up a narrow view and focusing on learning goals as the only outcome is not sufficient or realistic. It is important to understand that students pursue multiple goals of equal importance and even though in-class multitasking might affect their learning goals adversely, their increased productivity in their other tasks can make it worthwhile for them. Therefore, there is a need to support this widespread behavior in online classes rather than eliminate it altogether.

2.3 Existing Designs for Multitasking

Many interventions for self-control and self-regulation have been proposed to reduce multitasking. In a review of digital self-control tools, Lyngs et al. [30] divide these strategies into 4 main categories, block/removal of distractions, self-tracking of activities, goal advancement, and reward/punishment. In an example of self-tracking interventions, Lottridge et al. [29] designed a browser plug-in that divides browser tabs into work and non-work and tracks the time spent on each category and displays it to the user to reduce time spent on non-work tasks. PomodoLock [23] is an example of a blocker intervention that blocks interruption sources across multiple devices to avoid self-interruption.

In a completely different approach in a recent study, Son et al. [40] embrace the inevitability of multitasking and accept distractions as a natural component of online meetings. They demonstrate the effectiveness of real-time transcription to support multitasking. With the prevalence of in-class multitasking in online classes, there are few existing design solutions that support multitasking, and improving learners' experience by optimizing the multitasking trade-off remains an important design problem that needs to be addressed by HCI researchers.

3 FORMATIVE PILOT STUDY

Most of the existing studies on in-class multitasking set the learning goal as the reference and therefore dismiss its potential positive outcomes in fulfilling other goals. With clear evidence that students, engage in this behavior, we sought to understand their motivations and to learn more about their perceptions of multitasking and the challenges it poses for them. The insights gained in this exploration set the scope and served as the foundation for our design.

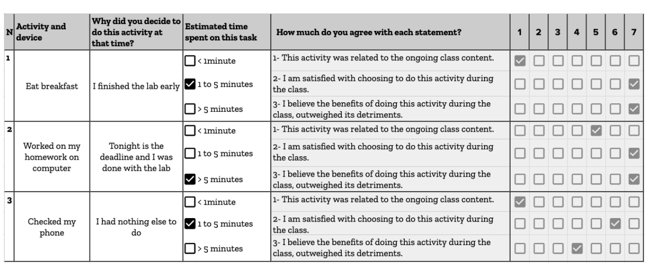
3.1 Participants

We recruited 10 participants (3 male, 7 female) between the ages of 18-24 who were undergraduate or graduate university students who are currently enrolled in at least one online synchronous course. Of our participants, 6 were undergraduate and 4 were graduate students enrolled in different programs such as Engineering, Arts, and History. The participants were recruited using convenience sampling and were compensated 20 CAD for their participation in the study. All 10 participated in at least one session of the diary study and 8 out of 10 participants consented to participate in a follow-up semi-structured interview.

3.2 Method

We conducted a diary study where students kept records of their multitasking activities during their online synchronous classes. We chose to conduct a diary study because of its high ecological validity [10] and more reliable data collection due to the in situ nature of recording data.

The participants were given a diary template to fill out during their online synchronous class. They were asked to record all the tasks they did during the class that were not a part of the main class activity. For each task, they were asked to write the title, the device they used for performing the task (mobile, laptop, notepad, etc.), why they chose to do that task, and their time estimate for the task duration (less than 1 minute, 1-5 minutes, more than 5 minutes). They were instructed to record the information immediately after engaging in the task, to reduce memory effects. After the class, the participants answered three Likert-item questions that asked about the relevance of the task to the classroom, the student's satisfaction with choosing to do this task during the classroom, and if they believed the benefits of doing this task during the class outweighed its detriments. One example of the filled-out diaries from our study can be found in Figure 2. Participants kept a multitasking diary for 2 or 3 online synchronous lectures.



N	Activity and device	Why did you decide to do this activity at that time?	Estimated time spent on this task	How much do you agree with each statement?	1	2	3	4	5	6	7
1	Eat breakfast	I finished the lab early	☐ < 1minute	1- This activity was related to the ongoing class content.	☑	☐	☐	☐	☐	☐	☐
			☑ 1 to 5 minutes	2- I am satisfied with choosing to do this activity during the class.	☐	☐	☐	☐	☐	☐	☑
			☐ > 5 minutes	3- I believe the benefits of doing this activity during the class, outweighed its detriments.	☐	☐	☐	☐	☐	☐	☑
2	Worked on my homework on computer	Tonight is the deadline and I was done with the lab	☐ < 1minute	1- This activity was related to the ongoing class content.	☐	☐	☐	☐	☑	☐	☐
			☐ 1 to 5 minutes	2- I am satisfied with choosing to do this activity during the class.	☐	☐	☐	☐	☐	☐	☑
			☑ > 5 minutes	3- I believe the benefits of doing this activity during the class, outweighed its detriments.	☐	☐	☐	☐	☐	☐	☑
3	Checked my phone	I had nothing else to do	☐ < 1minute	1- This activity was related to the ongoing class content.	☑	☐	☐	☐	☐	☐	☐
			☑ 1 to 5 minutes	2- I am satisfied with choosing to do this activity during the class.	☐	☐	☐	☐	☐	☑	☐
			☐ > 5 minutes	3- I believe the benefits of doing this activity during the class, outweighed its detriments.	☐	☐	☐	☑	☐	☐	☐

Figure 2: An example of a diary template filled by one of the participants in one session of an online class.

After their participation in the diary study was finished (in 2 or 3 sessions of online class), the participants were invited to a remote semi-structured interview session on a video conferencing platform where they were asked about their motivations, perceptions, and challenges concerning in-class multitasking. To analyze the data, we performed reflexive thematic analysis [6] on the diary entries and the interview transcripts.

3.3 Findings

In the diary study, 10 participants kept multitasking diaries in 22 sessions of online synchronous classes. The session lengths were between 1-3 hours. Overall 106 diary entries were recorded across these 22 sessions. On average, each participant entered 5.08 (range 2 to 8.5) tasks/session. Of the 106 multitasking sessions logged, participants estimated that 22% took longer than 5 minutes, 38% took between 1-5 minutes and 40% took less than 1 minute to finish. In terms of device and medium for multitasking, 43 multitasking entries (41%) were done on a computer, 21 entries (20%) were done on a phone, 35 (33%) used neither computer nor phone (e.g. talking to my sister), and 7 entries (7%) did not specify. Finally, in 78 (74%) of the diary entries, the participants disagreed or strongly disagreed with the statement *"This activity was related to the ongoing class content."*, indicating that the majority of the participants' in-class multitasking was unrelated to the lecture content and activity. Our results confirm the prevalence of in-class multitasking and support the need for addressing it as a significant part of the learning experience in online classes.

3.3.1 Motivations for Multitasking. We discovered the following themes for the participants' reasons and motivations for multitasking.

Low importance of learning content: In our diary entries, the participants expressed the low importance of the learning goal as the reason for their multitasking in many instances. This theme was observed in 20 entries (19%). They expressed this in terms of the class or the topic being "slow" or "boring", or that they were "not interested" or "already knew the content", etc. In the follow-up interviews, we delved deeper into why the participants found the learning content of lower importance. We discovered that the main theme behind this seems to be *perceived ineffective learning*. The content delivery and the participants' prior background are important factors that can make the lecture content either too easy or too difficult for them to learn. In both situations, this can lead to them feeling like they are not learning effectively and motivates them to do other tasks during the lecture. P5 said *"I couldn't understand the topic during the class and it was too hard and I couldn't catch up. So I gave up and stopped listening and did something else."*. Furthermore, a common theme mentioned by six out of eight participants is *peer activity*. It appears that the participants did not find their peers' involvement in the classroom as important as the instructor's teaching. The activities mentioned were peer questions (*"Sometimes students ask questions that I find irrelevant and something that I'm not interested in."*) and discussion sessions (*"[I multitask more] When it's open-discussion vs actual instruction"*).

High importance or urgency of task: One of the main themes observed in the multitasking diary entries was an emphasis on the high importance of their task. The participants used words such as "urgent", "necessary", "needed to", and "had to" to express the importance of the task being their rationale for doing it. The reasons for 26 entries (25%) fell under this theme. Our findings in our interviews support this. Seven out of eight participants talked about how having more important commitments makes them choose to engage in in-class multitasking.

External interruptions: External interruptions [21] were another main culprit for the participants' in-class multitasking in 15% of the diary entries. They reported receiving notifications, getting calls, and other people speaking to them as their reasons for multitasking under this theme.

Self-interruptions: Self-interruptions which are initiated internally [21] the main reason for the participants' multitasking in 16% of the diary entries. Some examples of self-interruptions in the participants' diaries are expecting a message or an event so checking to see if they received any (e.g. "I was curious if I had gotten any new emails."), mental or physical fatigue, hunger, and thirst.

We understand positive and beneficial in-class multitasking to be prompted by a combination of these themes. An internal or external interruption as a *trigger* combined with the low importance of learning or the high importance of the task as the *underlying reason* are conditions that can lead to a switch from the learning task to the secondary task. An example to illustrate the combined effect of these factors is when a student receives a notification on their phone (trigger exists), but because they find the lecture content important and the secondary task as not important (underlying reason does not exist) they do not choose to multitask.

3.3.2 Perceptions of Multitasking. Our results for the Likert scale questions in the diary study showed that in 71% of the multitasking entries, participants agreed to an extent (they chose somewhat agree, agree, or strongly agree) that they were satisfied with choosing to do that task during the class. In 63% of the entries, participants agreed to an extent that they believed the benefits of doing that task during the class outweighed its detriments (Figure 3). This shows that even in retrospect, participants found the majority of their multitasking activities beneficial and did not regret engaging in them during the class.

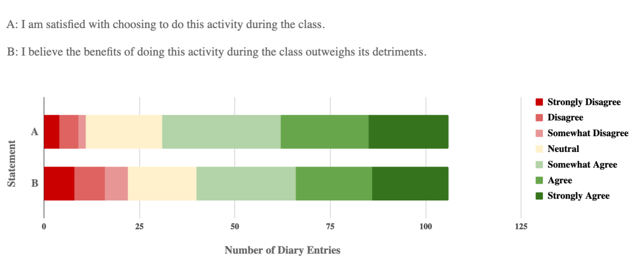


Figure 3: In 71% of the diary entries, participants agreed to an extent that they were satisfied with choosing to do those tasks during the class, and in 63% of the diary entries, participants agreed to an extent that the benefits of doing the task during the class outweighed its detriments.

In the follow-up interviews, participants provided more details about the benefits of in-class multitasking. Six out of eight interviewees believed that in-class multitasking helps them save time when they are not learning from the class. P1 said *"..I will use my time in an efficient manner rather than just listening to the subject that I already know about."* . Participants expressed that they can benefit more from in-class multitasking in online classes as they are not restricted by the social norms in traditional in-person classes. P9 said *"In in-person classes I don't feel comfortable or appropriate to check my phone when I'm waiting for my classmates to finish their work but at home, it's easier."*. P1 also expressed why they prefer online classes for increasing their productivity *"I prefer online because, for a class like this, I think if I had to do it in person I would lose so many hours [by not multitasking]"*.

In addition to increasing productivity, some participants indicated that in-class multitasking helps them concentrate on the lecture content. P10 said *"Long and discussion-based classes make it very hard for me to pay attention, so when I'm multitasking I am able to pay attention better because I am stimulated in other ways rather than just auditory stimulation."*.

3.3.3 Challenges of Multitasking. We inquired about the participants' challenges in in-class multitasking and classified our findings into two main categories: *1. cognitive consequences*, and *2. metacognitive consequences.*

Based on our findings, one of the main challenges of in-class multitasking is *content loss.* P9 said: *"[the problem is] Feeling like I'm missing out on the class even though I chose to multitask because I felt like I wouldn't be missing out."*. Missing context when switching between the learning task and the secondary task is another discovered cognitive consequence of in-class multitasking. The participants had a hard time catching up to the lecture content when they came back and found their minds occupied with other tasks. P8 said *"When you switch your attention to another task and then go back to the class, I lose focus and find it difficult to concentrate. Since the topics are very different it's hard to switch attention."*.

Following the content and context loss due to in-class multitasking, participants had to spend extra time after class to compensate for their multitasking. P2, P3, and P8 mentioned watching lecture recordings as a way to recover missed information. We group content loss, context loss, and learning overhead as cognitive consequences of in-class multitasking as they all affect the participants' learning directly. However, they also mentioned how in-class multitasking affects their metacognition (knowledge and regulation of one's cognitive processes [28]), which in turn influences their learning.

Based on our interviews, it is a common occurrence for the participants to spend too long on other tasks and forget to get back to class in time. P9 talks about bad time management due to multitasking: *" .. and you think you've been playing 1 or 2 minutes but in reality 10 minutes have passed."*. Task wandering is another reason mentioned for late returns to the classroom. P9 said *"Once I get distracted and check one email and then read another email and before I know it I'm not listening to the class anymore."*.

Another reason for the participants' untimely return to the learning task, is poor attention management. When engaged in in-class multitasking, they rely on auditory cues that signal a change in topic or activity to know when they need to switch their attention to the learning task. However, they sometimes miss these cues and are unable to get back to class on time. P3 said *"If I'm not completely distracted, if I hear key words like: "OK, let's move on" I go back to* *the class but sometimes I miss that and I realize that the part that wasn't interesting to me is done."*.

To summarize some of our findings from the formative pilot study, we learned that:

- Perceptions: Participants were mostly satisfied with their choice to engage in in-class multitasking and found it beneficial.
- Motivations: Participants evaluated the importance of the learning task and the secondary task(s) and made a conscious choice to multitask accordingly.
- Challenges: Participants found in-class multitasking challenging due to its negative consequences for their learning outcomes.

4 DESIGN

Our findings from the formative pilot study led us to R0 as the overarching requirement. **R0. Support students' positive in-class multitasking by mitigating its adverse effects on learning outcomes.**. With the prevalence of in-class multitasking in online learning and students' positive outlooks on it, eliminating multitasking is not a reasonable solution. Therefore, we aim to support learners in engaging in positive multitasking and benefiting from it while reducing its potential negative influence on their learning.

As seen in Figure 4, following R0, the two next design requirements, R1 and R2, are derived from the discovered cognitive and metacognitive consequences of in-class multitasking.

R1. Enable immediate recovery of missed content in the class time frame. Focusing on the discovered cognitive consequences of in-class multitasking, providing the ability to review missed content immediately compensates for content loss and prevents context loss. Enabling the recovery of missed content in the class time frame also reduces the need for spending extra time after the class to recover from in-class multitasking.

R2. Provide assistance in metacognitive monitoring in in-class multitasking by allowing topic, activity, and time-based offloading. Students' lower metacognition due to multitasking can be mitigated by allowing for metacognitive offloading.

4.1 Designing for Cognitive Consequences

Based on R1, we propose a set of design elements (see Figure 4) and create a prototype based on these design elements that we call *"Time-Turner"* (Figure 1). In the following section, we describe the mentioned design elements and how they were prototyped by describing the user flow.

4.1.1 D1. Bichronous Learning: Asynchronous Viewing in Synchronous Settings.

Research shows an inherent difference between synchronous (e.g. in-class multitasking) and asynchronous (e.g. homework multitasking) settings [4]. When multitasking in synchronous online classes, students often miss critical information and are not able to recover the missed information until after the class. However, in asynchronous settings, it is easier to continue the preliminary task from where there were left off after returning from multitasking.

Bichronous learning refers to a combination of synchronous and asynchronous content delivery in online learning[32]. We propose to create a unique bichronous learning environment by introducing asynchronous viewing during an otherwise fully synchronous online class. We provide real-time access to the lecture recordings and allow students to rewind, pause, and skip forward in the recording as they would in an asynchronous class, immediately after they return to the class from their multitasking to mitigate content loss and prevent context loss. The audio control provides the option to listen to the lecture in the background or mute the audio when multitasking based on user preference.

4.1.2 D2. Visualization of Temporal Information.

Bellur et al. also mentioned that Knowing what has been missed is a key challenge for multitaskers [4]. Therefore, it is important to provide information about what parts of the class have been missed and what parts have been watched so that students are able to review the missed content efficiently. Furthermore, having the freedom to access past content asynchronously in a live class means that the user needs to know their temporal location and that of the live class at the same time.

We provide a progress bar that spans the estimated length of the lecture and indicates the watched content as filled in and the missed content as gaps (Figure 5). When the user leaves the class window to work on another tab or window, the system detects their absence automatically and stops filling in the progress bar until they return. The user can scrub to the beginning of the gaps to watch the missed content asynchronously. If the student wants to multitask on another device, they have the option to press the pause button. After returning to the class, they can press play and watch the missed content asynchronously from where they left off. To provide information about the synchronous class in the asynchronous mode, we include a picture-in-picture view of the synchronous class in case the user needs to be aware of the content. The window can be minimized if found distracting.

4.1.3 D3. Guided Accelerated Asynchronous Viewing.

Learning overhead refers to the extra time that the students need to spend on learning after the class. Accelerated asynchronous viewing offers a solution to ensure that students recover the missed content immediately and catch up to the live lecture before the end of the class. Students are able to watch content with a faster playback speed set to a default value of x1.5 at the start. The user is able to adjust the speed based on the content and their comfort to maximize their efficiency. However, choosing the right playback speed might present a new challenge for students if they wish to be caught up to the lecture before a *target time*. We define a target time as a point in the lecture when the student anticipates an event that requires them to be caught up and present in the live lecture, for example, for an in-class quiz or by the end of the class period. The interface calculates the minimum playback speed required to catch up to the synchronous class before the set target time and guides the user in adjusting their pace to ensure the right amount of time spent in the asynchronous mode.

The user can set a flag on the progress bar to indicate their target time. When they begin watching in the asynchronous mode, the time distance between the asynchronous and synchronous headers will show up on the progress bar, showing the user how long it will take for them to catch up to the synchronous lecture with the current playback speed. If the current speed is too slow to catch up before the target time, the text will turn red and start blinking,

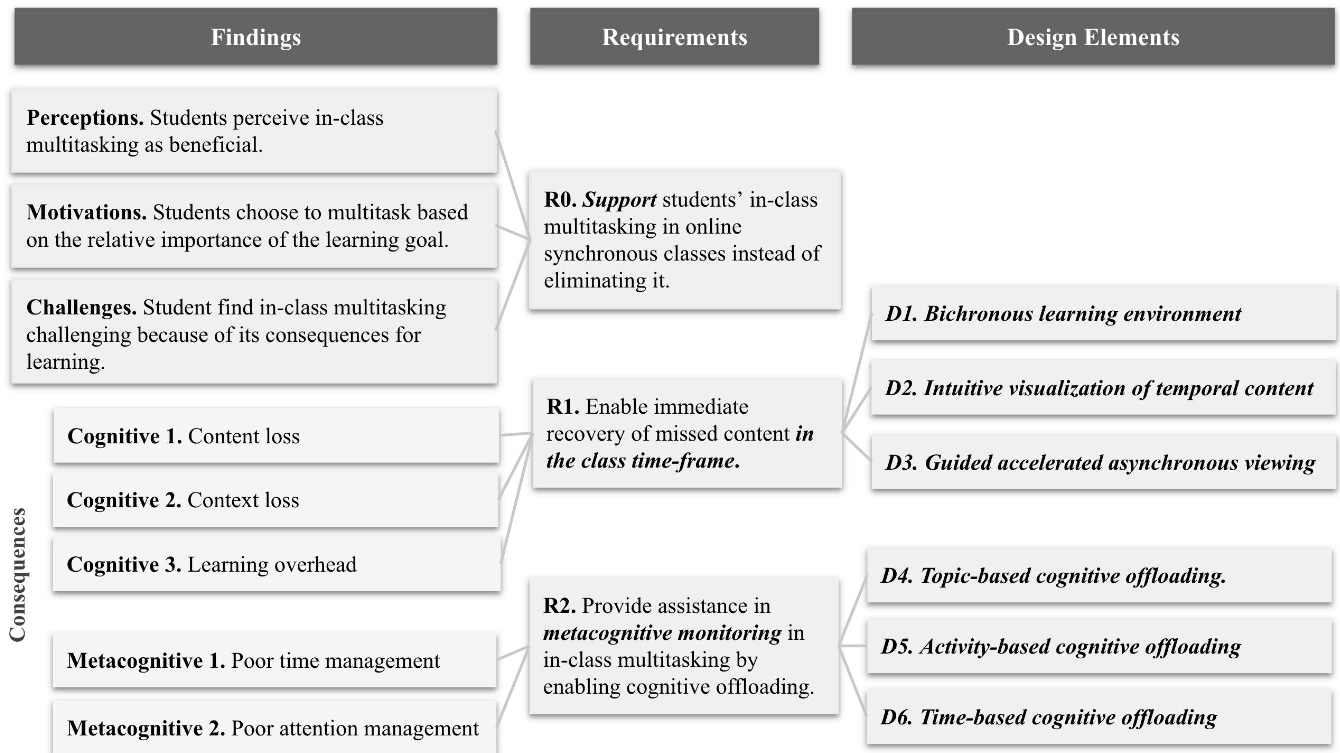


Figure 4: Based on our findings from the formative pilot study on students' perceptions, motivations, and challenges in in-class multitasking, we define our overarching requirement as supporting in-class multitasking instead of eliminating it. Based on our categorization of student's challenges into cognitive and metacognitive consequences, we elicit R1 and R2 as our design requirements and define D1-D3 as our cognitive design elements and D4-D6 as our metacognitive design elements.

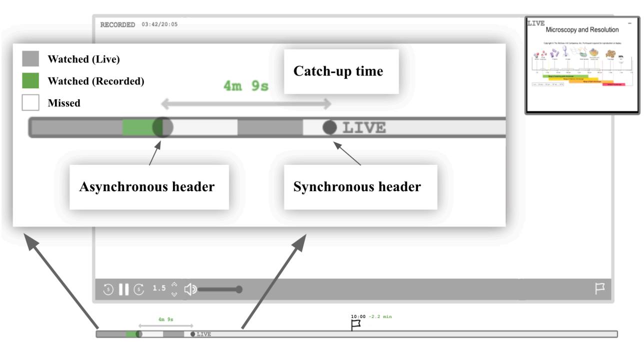


Figure 5: The augmented progress bar in Time-Turner (enlarged), shows the users where they are in time (asynchronous header), where the live class is in time (synchronous header), and how long it takes for the user to catch up to the live class. The progress bar provides information on the content that was watched in live mode, watched in recorded mode, and was missed due to multitasking.

indicating a need to increase the playback speed. The student can adjust their pace until the text turns green showing that they can catch up to the class before the target time with the new speed (see Figure6).

4.2 Designing for Metacognitive Consequences

Cognitive offloading is the use of physical action to alter the information processing requirements of a task to reduce its cognitive demand [35].To address R2, we propose supplementary design elements that focus on enhancing students' metacognitive monitoring in in-class multitasking by providing cognitive offloading.

4.2.1 D4. Integrated Lecture Slides as Topic Handles for Topic-based Offloading. The class topic is an important factor driving students' multitasking. When distracted with another task, students' awareness of the lecture topic is reduced and they are not able to detect any topic change occurring. As a result, missing more content than they had intended is an unwanted consequence of in-class multitasking.

We propose to provide information about future topics to students to help them with their planning and monitoring in the process of multitasking. Providing access to lecture slides before the class is common practice with most instructors and is shown to improve students' overall attendance and participation [3] and more efficient encoding of the lecture [31]. We recognize that lecture

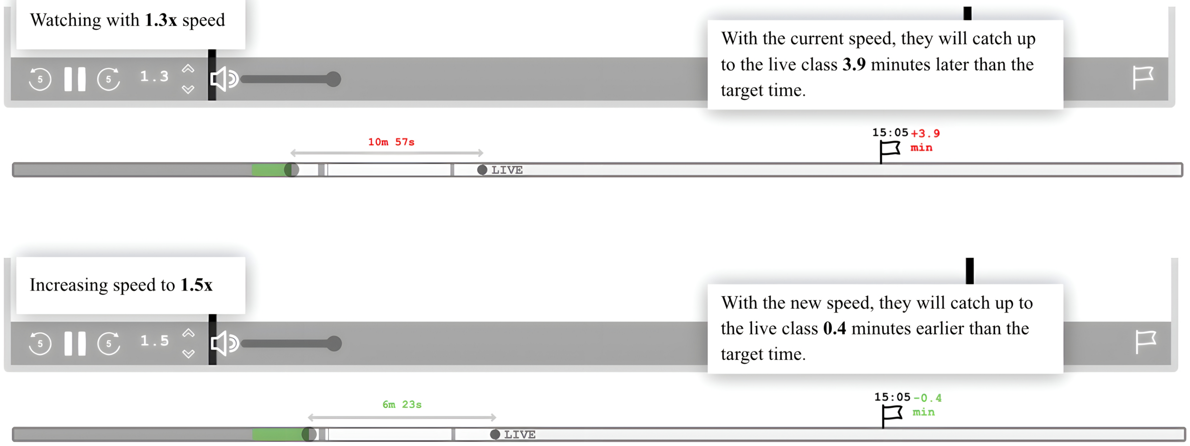


Figure 6: Top: The student is watching the lecture asynchronously with 1.3x speed. With this speed, they will catch up to the live lecture 3.9 minutes later than the target time they had set. Time-Turner prompts them to increase their speed by showing the time difference in red color and blinking. Bottom: After the student increases the playback speed to 1.5x, they are now able to catch up to the live lecture before the target time and the time difference is shown in green.

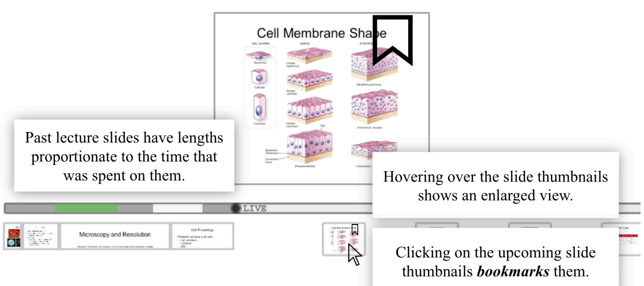


Figure 7: Before a student starts to multitask, they can hover over the upcoming slide thumbnails to learn what the future topics are. If they want to be back when a certain topic comes up, they can click on the thumbnail for the slide to *bookmark* it. When that slide shows on the screen, they will get a notification to pay attention to the class.

slides are a good representation of the topics discussed in the classroom and therefore choose to integrate them into the lecture as alert handles. Assuming that the user uploads the lecture slides to the interface before each class, the future slides are shown as thumbnails underneath the progress bar in a discreet equally spaced format (Figure 7). By hovering over each thumbnail, it will increase in size and show a clear view of the upcoming slide. As the lecture proceeds, the past and current thumbnails change to a continuous bar with their lengths visualizing the time spent on that lecture slide proportional to the full class duration. The thumbnail bar and the progress bar are coupled in the sense that the part of the progress bar right on top of each of the current and past lecture slides is the time spent on that slide, allowing students to scrub to each topic quickly if needed.

To enhance students' metacognitive monitoring, we allow users to "bookmark" future slides that they need to be present for (topic alert). When the said topic/slide comes up, they will receive a notification to let them know about the topic change.

4.2.2 D5-D6. Activity-based and Time-based Offloading. Multitasking inhibits students' awareness of class activities that might require a switch back to the learning task. To assist with their monitoring of class activities, we propose more reliable activity alerts that notify the students when a question is being asked or a discussion starts in the live class. The student can turn on activity notifications to get notified of the activity changes occurring in the classroom.

To address the inhibition in time management due to multitasking and distraction, we provide students with quick and easy-to-set time alerts. To ensure that they spend only a short time away from the class, users can click on the time alert button once to set a quick 1-minute timer that shows up on the progress bar. Clicking on the button twice will set it to two minutes and so on. When the time is up, the user will hear a notification reminding them to get back to the class. This design element can be useful for people who tend to spend longer on multitasking than they originally anticipated.

5 EVALUATION

To find out if the proposed design elements are effective in mitigating the adverse effects of in-class multitasking on learning, we conducted a human-subject user study.

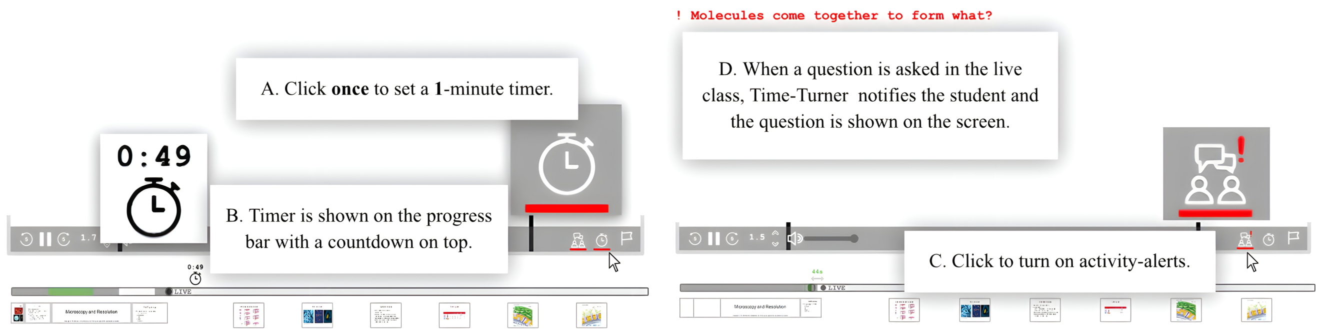


Figure 8: Left: Time-based activity offloading. A) The student can click on the timer button to quickly set a 1-minute timer, click twice to set a 2-minute timer, and so on. B) The timer shows up on the progress time at the temporal location that it is set for. Right: Activity-based offloading. C) The student can enable activity alerts by clicking on its button. D) When a question is asked in the live class, the student is notified and can read the question on the screen.

5.1 Evaluating the Cognitive Design Elements

We prototyped Time-Turner as a proof of concept for the cognitive design elements, D1, D2, and D3 (Figure 4). Our goal is to compare the user's learning outcome when multitasking during a synchronous learning activity simulating an online class across the baseline system and Time-Turner.

5.1.1 Participants. We recruited a convenience sample of university students (undergraduate, graduate, post-doc) using the platform Prolific (www.prolific.co). In order to eliminate the effects of the language barrier on learning, we screened participants for being native English speakers. Our final participant list consisted of 20 university students between the ages of 18-44 (10 men, 8 women, 2 non-binary/transgender) from a variety of majors (engineering management, computer science, law, mathematics, religion and folklore, criminology, marketing, acting, accounting, and English literature). We did not include participants from our previous study to prevent bias.

5.1.2 Method. To validate our cognitive design elements, we conducted a within-subject comparison with a baseline condition. The baseline interface simulates an online live lecture as typically experienced with online learning platforms. Our experiment consists of three main parts: 1. the primary task (watching the lecture), 2. the secondary task (multitasking), and 3. the post-lecture quiz (learning evaluation). Three rounds of pilot testing were performed to improve the validity of the experiment settings.

In Bloom's taxonomy [5], knowledge (the ability to remember what has been learned) and comprehension (the ability to interpret meanings and concepts) are the two first levels of learning outcomes. Because of the challenges in measuring comprehension in a short time, and evidence of in-class multitasking showing a stronger effect on memorization compared to comprehension [18], we chose a memorization-based learning task. To preserve ecological validity, we used two recorded lectures from an actual university-level introductory Biology course [42]. The recordings were analyzed for information density and level of difficulty by the investigators and in pilot tests to minimize confounding factors. Furthermore, the lecture videos that were used across the two conditions and the temporal order of the conditions were fully counterbalanced. It is important to note that our primary task was a simulation of learning in a live class and the participants did not attend a real live lecture.

We designed our secondary task to create a high cognitive load to ensure the cognitive consequences of multitasking. We created a set of five reading comprehension questions framed as an English assignment that the student needs to finish before its deadline. Each question consisted of a passage, 3-4 lines long, and two questions, one comprehension question (e.g. When was the French Revolution?) and one counting question (e.g. How many words are there in the second sentence?). Based on our pilots, providing two types of questions proved to be effective in minimizing the learning effect that came after answering multiple reading comprehension passages. To ensure equal time spent on the secondary task in both conditions, the participants had 30 seconds per passage totaling 150 seconds in total.

Finally, to measure the student's learning outcomes, we created a quiz from the lecture content. To provide full coverage of the lecture content, the quiz was designed as 30 true/false statements. The participants were also given the option to choose "I knew the answer to this question before watching this lecture.". All questions with this answer were removed from the quiz and final grade calculations. To increase the reliability of the learning outcomes, we dissuaded participants from guessing an answer, by penalizing incorrect responses in the stated grading scheme: -1/3 points are assigned to wrong answers, +1 points to correct answers, and 0 points to questions left blank.

5.1.3 Procedure. The experiment was conducted remotely and took approximately 1 hour. Each user was asked to watch an instructional video that introduced the design elements of Time-Turner. A shorter version of the experiment was provided as training for students to ensure their familiarity with using Time-Turner and the experiment procedure. The experiment consisted of watching a 10-minute online biology lecture (simulated as a synchronous class), multitasking for a fixed 2.5-minute-long window of time during the lecture, and taking a quiz on the lecture content after the lecture was over. These steps were repeated once using the baseline interface and once using Time-Turner. Following the experiment, the participants were asked to fill out a survey to collect qualitative feedback on the design.

5.1.4 Results. **Time-Turner, improves students' total memorization-based learning outcomes when they engage in multitasking.** In a two-tailed paired t-test analysis, we observed a significant improvement in students' percent grades when using Time-Turner compared to when using the baseline system ($p < 0.05, t(19) = 2.53$) during the simulated online lecture. The mean grade across the whole test increased by 7.5% when using Time-Turner compared to the baseline. To find the effect size we calculated Cohen's D to be 0.46 showing a close to moderate effect (See Figure 9). Participants reported prior knowledge by choosing "I knew the answer to this question before watching this lecture." for a mean value of 1.67 ($SD = 4.89$) percent of the questions. The percentages of questions that were removed due to prior knowledge across our two conditions are as follows: Time-Turner $M = 1.83$, $SD = 6.07$; baseline $M = 1.5$, $SD = 3.5$.

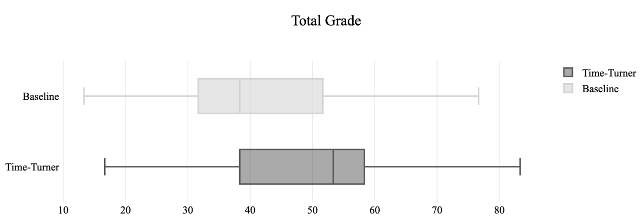


Figure 9: There was a significant improvement in students' percent grades when using Time-Turner compared to when using the baseline system ($p < 0.05$, $t(19) = 2.53$). The mean grade across the whole test increased by 7.5% when using Time-Turner compared to the baseline.

We performed the same comparison for students' grades in the multitasking and non-multitasking sections. Our two-tailed paired t-test analysis on the multitasking sections' grades also showed significant improvement when using Time-Turner compared to the baseline ($p < 0.05$, $t(19) = 2.12$). The mean grade across the multitasking section increased by 13.3% when using Time-Turner compared to the baseline. This shows that students were able to mitigate the content loss that occurred because of their engagement in the second task and suggests that Time-Turner can be an effective intervention. We perform a two-tailed paired t-test with the null hypothesis being no significant difference in students' performance in the non-multitasking section across the two conditions. Our results show that there is no significant difference observed across the two conditions ($p = 0.65, t(19) = 1.58$) and therefore show that watching content in the non-multitasking sections with a faster playback speed in Time-Turner does not reduce students' learning outcomes. After the participants had the chance to use the features in Time-Turner in two trial lectures and two main lectures, they were asked to fill out a questionnaire about their opinion on the prototype and its features. Our results show strong positive attitudes towards Time-Turner. Out of 20 participants, 10 strongly agreed, and 9 somewhat agreed that they find Time-Turner helpful

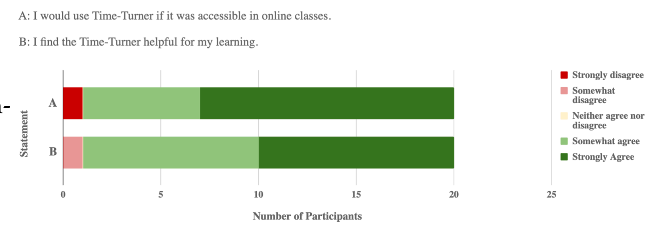


Figure 10: 95% of participants strongly or somewhat agreed that they would use Time-Turner if it was accessible in their online classes. 95% of participants strongly or somewhat agreed that they find Time-Turner helpful for their learning.

for their learning. Only 1 participant somewhat disagreed with this statement. Thirteen participants strongly agreed and 6 somewhat agreed that if Time-Turner was accessible in their online classes, they would use it. One participant strongly disagreed with this statement.

5.2 Evaluating the Metacognitive Design Elements

To evaluate D4, D5, and D6 (Figure 4), and compare them with Time-Turner, the second part of the study was a follow-on qualitative survey user study.

5.2.1 Participants. We contacted all 20 participants from the previous experiment through Prolific and invited them to participate in a follow-up survey user study. Nine participants (5 women, 4 men, ages 18-44) consented to participate. The survey study took around 30 minutes and was done separately from the previous experiment.

5.2.2 Method. The questionnaire had 4 main sections: Time-Turner (D1-D3), topic-based alerts (D4), activity-based alerts (D5), and time-based alerts (D6). We included Time-Turner to be able to compare the perceived effectiveness of the metacognitive design elements to the design guidelines proposed in Time-Turner.

In each section, the participant is asked to watch a video that introduces the feature and explains how to use it. After watching the video, they are given a multitasking scenario where the given feature can be used. The participant is asked to imagine themselves in this scenario and use (or not use) the given feature as they would in real life. They were then asked open-ended questions about their likes and dislikes in this feature and other scenarios they would find this feature useful. Following the open-ended questions, they were asked four 5-point Likert scale questions: *1. I find this feature easy to use., 2. I find this feature helpful., 3. I would like to have this feature in my online classes., 4. I would use this feature if it was available in my online classes.*

5.2.3 Results. The results of the survey are shown in Figure 11. Our results show us that the metacognitive design elements are not perceived to be as effective and helpful as the cognitive design elements proposed in Time-Turner. However, they still show promise as the participants found them mostly easy to use and helpful, and showed interest in having them in their online classes. Based on our qualitative feedback on these features, there is potential in addressing the metacognitive challenges of in-class multitasking by providing cognitive offloading.

Topic Alerts. Participants mostly expressed interest in being able to multitask in parts of the lecture that were not beneficial to them. One participant remarked on how easy it is to find different sections of the class with this feature: *"I like that this feature minimizes the amount of time a student needs to spend looking for the required lecture sections."*. Finally, an interesting comment highlighted how lecturers' involvement can increase the benefits of this feature by giving pings at the start of different topics based on the content: *"I like that you can set the bookmarks to plan your attention during the lecture according to the slides but it may also be useful to allow lecturers to give different pings at the start of different topics to allow students to tune in."*.

Time Alerts. Six out of 9 participants found the time-based alerts useful as a reminder to get back to the class on time (*"It would be useful if you have a quick task to complete but may be easily sidetracked and need a reminder to return to the lesson."*). One participant also mentioned that they liked how easy it was to set up and use. However, the other 3 participants did not find this feature helpful because they did not find it to be a realistic solution. One participant said that they think it doesn't make sense for them to use this feature as it will take longer to plan ahead compared to multitasking quickly without any planning. Another participant expressed how using a timer creates extra pressure and is counter to the other design elements provided to support flexibility. They said: *"Perhaps setting rigid time limits on a program that is designed around flexibility and productivity may be counter-intuitive. The addition of a timer may be needlessly pressurizing."*. For many students, in-class multitasking is something that occurs unplanned and unexpectedly. Therefore, providing means to recover from their in-class multitasking, after they do it, is more reasonable than providing means for planning for it ahead of time.

Activity Alerts. Participants were interested in the ability to engage and participate in class activities even when they are multitasking. One participant mentioned *"I like that this could help with engagement in online classes. For instance, when a poll has to be taken but a student is busy with other tasks."*. However, two participants mentioned that even when notified of the class activity, it is difficult to learn the context quickly enough to be able to participate in the discussion. So a mechanism to provide quick context for students in this situation is required. Another factor that was brought up was whether or not class participation was part of the lecture. One participant disagreed with "I would like to have this feature in my online classes." because they did not need to participate in class activities in their online classes and therefore did not find a need for this feature.

6 DISCUSSION

6.1 Supporting In-class Multitasking

In our evaluation of the cognitive design elements, we demonstrated that Time-Turner is successful in mitigating the cognitive consequences of in-class multitasking and improving the students' memorization-based learning outcomes compared to a baseline. This, combined with the very positive feedback from the student participants shows that supporting in-class multitasking can indeed be an effective approach to improve university students' learning experience.

When multitasking in a traditional online lecture, depending on the complexity of the secondary task, students may be able to partially process auditory or visual content from the lecture. In our evaluation of Time-Turner, participants were able to listen to the lecture in the background when multitasking in both conditions. If a participant chose to listen to the lecture while multitasking, using Time-Turner to review the missed content would allow them to process the content twice, leading to improved memorization-based learning.

A potential argument against our proposed design is that watching the content with a faster playback speed may lead to a decline in learning. To investigate this, we looked into the existing research. One study [36] shows that watching videos up to 2x the original playback speed has minimal costs for learning. In another study [25], it is shown that students who watch accelerated content with an increase to 1.25x speed, are more likely to have better grades. This is evidence that not only watching the lecture content asynchronously and with a faster playback speed does not impair students' learning outcomes, but it might also lead to better learning and performance for them.

6.2 Supporting Students' Autonomy

Our approach in this research is in contrast with the traditional belief that in-class multitasking should be prevented at all times. Despite the abundance of evidence for the negative consequences of in-class multitasking for learning, university students' persistence in engaging in it shows us that it is perceived to be beneficial and our results from the formative pilot study confirm this. In a study by Niterman et al. [37], university students were asked whose job they think it is to minimize off-task technology use in the classroom. They found that students view off-task and on-task technology use in the classroom as an informed and personal choice.

While academic goals are some of the most important goals in a university student's life, it is extremely important to recognize that they are not their only goals. University students are adults with many different social and personal goals as well as their academic and professional goals. Our formative pilot study showed us that the participants took it upon themselves to judge the effectiveness and importance of their learning and compared it to their other goals, leading to a conscious choice to multitask accordingly. Having autonomy over their learning can lead to higher productivity and satisfaction for university students. It is imperative for HCI researchers to take this into consideration and provide solutions for the challenges of in-class multitasking without disregarding students' autonomy over their learning and their decisions to pursue other goals when in the classroom.

6.3 Self-Paced Learning and Accessibility

In our study, using Time-Turner helped students mitigate the content loss that occurred because of their in-class multitasking. However, the benefits of this interface for students' learning are not

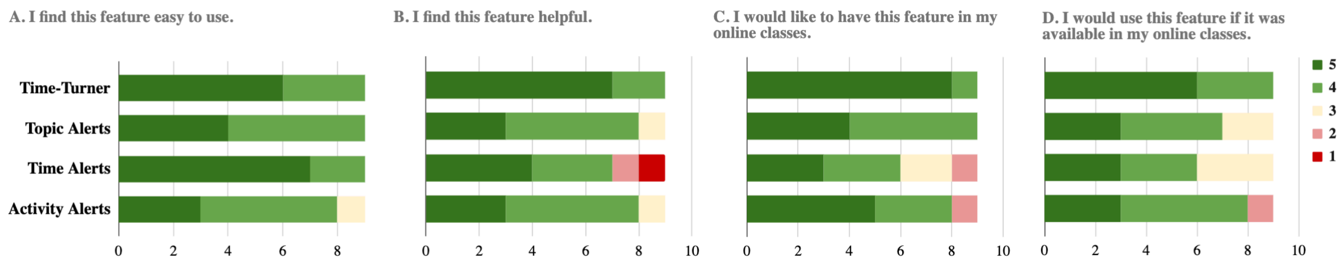


Figure 11: Likert-item questions in the qualitative evaluation of metacognitive design element (1 strongly disagree- 5 strongly agree). A. I found this feature easy to use. B. I found this feature helpful. C. I would like to have this feature in my online classes. D. I would use this feature if it was available in my online classes.

limited to multitasking. Students can use this interface for rewinding and re-watching sections of the class that they do not understand or learn very well when first listening to for any reason. They are able to review content as many times as they need until they feel confident that they have learned it well. While self-paced learning is mostly possible in asynchronous online classes where students take control of how long they wish to spend on each topic, combining asynchronous and synchronous modes and creating a unique bichronous environment in Time-Turner lets them take advantage of opportunities for self-paced learning in synchronous online classes.

As a result, this interface can potentially facilitate education accessibility. About 4.4% of adults between the age of 18-44 are diagnosed with Attention Deficit/Hyperactivity Disorder (ADHD)[22]. Students with this condition often have difficulty staying focused and paying attention when attending class. These distractions from listening to the lecture lead to significant content loss and impair their learning. Providing access to the proposed design elements prototyped into Time-Turner can allow students with ADHD or similar conditions to mitigate content loss due to attention deficit in the classroom.

6.4 Beyond Online Learning

Our research explored students' in-class multitasking and proposed solutions to support it by mitigating its negative outcomes. However, multitasking is a very common human behavior that is observed in many other settings. Existing research on multitasking in online workplace meetings points to similar issues [8]. Therefore, it is worth exploring these new contexts and the potential for supporting productive multitasking in them. Our proposed design elements can be applied in other similar situations where digital content and context loss are the consequences of multitasking.

Considering the positive results in our study for in-class multitasking in online synchronous classes, it is worth contemplating their effectiveness in in-person classes. Real-time streaming and recording of in-person lectures is a common practice. Considering the prevalence of laptop use by students in in-person classes, creating a bichronous learning environment where they are able to rewind and re-watch the recording of the missed content on their computers while present in the live in-person class is feasible. This provides opportunities for positive multitasking and self-paced learning in in-person classes.

7 FUTURE WORKS AND LIMITATIONS

Our research showed the potential of taking on a new approach to support in-class multitasking rather than prevent it by evaluating our proposed design elements. In a user study with 20 university students, we showed the positive effects of using our intervention on memorization-based learning when multitasking in a simulated online classroom. As these results might not portray students' behavior in real online university classes, our current findings motivate a longitudinal study with higher ecological validity and more participants to observe the effects of these interventions in true in-class settings. Additionally, collecting data on user interactions within our prototype as a future step can inspire other novel designs to improve students' experience with in-class multitasking.

As with many other tools, our solutions are not effective in all situations. Interactivity plays an important role in the effectiveness of our cognitive and metacognitive design elements. In an online class with a significant amount of synchronous interactive components, switching between the synchronous and the asynchronous modes can create stress and cognitive overhead for students. This provides grounds for more explorations in finding ways to support students' in-class multitasking in mostly interactive settings.

The qualitative evaluation of the metacognitive assisting design elements with a small sample size can be considered a preliminary step that motivates further research on these measures and how they affect students' quality of in-class multitasking and its effectiveness. Future research can study these factors quantitatively and qualitatively in realistic learning conditions. Furthermore, a small-scale formative pilot study was conducted to learn more about university students' multitasking in online synchronous classes and to structure our findings to better define our design process. A large-scale empirical study with a bigger sample size and wider demographic can lead to more insight into students' in-class multitasking habits and inspire more student-centered research on this topic.

Finally, it is worth mentioning that our research on students' in-class multitasking was solely centered around students' opinions and perceptions of this activity in light of the absence of this perspective in the existing research. However, instructors and lecturers are the other actors in the learning experience and their inputs and opinions on students' multitasking can provide new insights that can improve students' learning and multitasking. Studying the instructors' perspectives can be a valuable addition to the findings in this work.

8 CONCLUSION

Our contributions in this work are: (i) Demonstrating the effectiveness of supporting in-class multitasking through our proposed cognitive design elements prototyped in Time-Turner. The summative evaluation of our design (N=20) showed statistically significant improvement in learning outcomes when multitasking in online classes compared to a baseline. This was supported further by promising qualitative feedback. (ii) Structuring new findings and insights from our formative pilot study (N=10) to elicit requirements and novel design elements for supporting in-class multitasking. Finally, we evaluated our metacognitive design elements qualitatively (N=9) and set the groundwork for further exploration in the future. Our work presents a novel take on in-class multitasking and shows the potential benefits of supporting this common behavior instead of eliminating it.

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