# Exploring the Visuo-Vibrotactile Modality for Real-Time Low-Friction Student Feedback in the Classroom

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The benefits of student response systems (SRSs) for in-person classrooms are well-researched. However, all current SRSs rely on only a visual interface to relay information to the instructor. We describe the design and evaluation of Haptic-XCEL, a prototype system that uses an Apple Watch to deliver student feedback via both visual and vibro-tactile modalities to the instructor in real-time without delay. Based on in-class trials with a variety of University instructors, we found this system to be a true real-time solution for delivering student feedback, enabling better engagement from both the instructor and the students. We also identify opportunities to improve the Haptic-XCEL system based on the instructors' and students' experiences with our prototype, specifically in increasing system flexibility, accessibility, robustness against trolls, and possibly expanding to other modalities.

CCS Concepts: • **Human-centered computing → Field studies**; **Haptic devices**.

Additional Key Words and Phrases: Lecture feedback; student response systems; multimodal interfaces

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## 1 INTRODUCTION

Over the past few decades, the modern human has become a digitally multi-modal agent. The commercialization of smart watches, smart rings, and other smart wearables enabled people to interact with and perceive information via new modalities that are not purely visual. For example, smart watches can deliver different vibration patterns along with different types of information, allowing the user to tactilely differentiate what kind of notification they are receiving.

In this paper, we explore whether the Apple Watch's tactile modality can be an effective tool in enabling a speaker or performer to gauge and receive feedback from their audience in real-time. We specifically consider University instructors who, without the aid of technology, may find it challenging to assess student engagement and adapt their teaching in real-time to student needs. Student response systems (SRSs) like Slido, Mentimeter, Wooclap and others have been developed as solutions to this problem, yet these systems are limited to the visual modality and thus demand active visual attention from instructors. This is particularly problematic if the instructor's primary teaching method requires them to write on the board and face away from the students and the SRS's visual interface for extended periods of time. Therefore, we developed Haptic-XCEL (Haptic eXperiences for Continuous and Engaged Learning), a new student response system that consists of two components: a student-facing web application through which students can provide feedback to their instructor, and a watchOS application installed on an instructor's Apple Watch, relaying student reactions visually as emojis and tactilely as distinct haptic patterns.

We evaluated Haptic-XCEL in multiple courses during regularly-scheduled lecture time. Students reported that the system was more effective than others (like Slido and Mentimeter) in allowing them to communicate to their


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instructor the application's target reactions: confusion, confidence in understanding, and "raising my hand". The system's anonymous nature also encouraged students to participate in cases where they usually wouldn't without an SRS system present. Overall, the Haptic-XCEL system was generally easy to use, facilitated higher student engagement, better instructor engagement, and gave instructors valuable information to better regulate their lecture's pacing. We also synthesized multiple improvements to implement for the next iteration of the system, mostly to reduce the system's cognitive load for instructors as well as to prevent trolls and spammers.

## 2 RELATED WORK

### 2.1 Student Response Systems

Existing research supports the significance of constructive feedback to instructors for improving their teaching quality [10]. Specifically, immediate feedback is generally more beneficial than delayed feedback in facilitating learning [3]. To that purpose, different student response systems have been developed to enable the collection and visualization of live student feedback for instructors. While SRSs can help instructors gauge their student audience, the use of SRSs in the classroom has also shown to improve student motivation, activity levels, and engagement, with most research citing ease of use and anonymity as the most common student-reported reasons for these improvements. More specifically, ease of use lowers the barrier to interaction, and anonymity removes the fear of negative peer evaluation and the associated anxiety [13]. Studies have shown these positive results for popular applications like Slido [17] [12] [18] and Mentimeter [19] [11] [7], as well as more non-conventional ones like the LIM (Live Interest Meter) App [16] or Mudslide [5] which offer students alternative ways to communicate their questions or other thoughts during lectures. However, while the above systems successfully encourage student engagement, they all rely on sustained or frequent visual attention from the instructor. Since this is not always possible, the instructors' reactions to student feedback can be significantly delayed, especially if the instructors primarily use the blackboard and thus must face away from the student audience or any real-time feedback provided by an SRS via its visual interface.

No previous work in SRSs has addressed this issue, but there is clear potential that haptic technologies can effectively reduce communication latencies [14] in this space. We focus on building and evaluating an SRS that does not have to rely on a visual interface by also providing a vibro-tactile (haptic) modality.

### 2.2 Haptic Feedback

Studies in other domains have shown the value of haptic feedback in conveying information [4], with people being able to learn and distinguish between up to 10 distinct haptic patterns via smartwatches [1], phones [9], and even actuators installed on non-conventional part of the body such as a human's back [8]. Haptics have also been evaluated for vastly different audience and applications. For example, Khusro and colleagues explored the potential of phone-mediated haptic feedback for aiding the visually impaired in indoor navigation. The majority of the patterns were identified in less than 4 seconds. Four patterns achieved over 80% recognition, and two patterns surpassed 90% [9].

Generally, the research shows that well-designed haptic patterns can be used effectively to convey information, although more than four patterns may be too many for effective low-latency recognition. Despite such promising findings, there is a noticeable absence of research around the applications of haptic feedback in classroom settings. Based on previous research, we can expect haptic patterns to perform well in a classroom scenario where they would be used by students to deliver discrete information to instructors in real-time. Haptic-XCEL was built to test this hypothesis.

## 3 SYSTEM IMPLEMENTATION

The Haptic-XCEL system consists of two core components: a student-facing web application and a watchOS application installed on the instructor's Apple Watch. We also designed a researcher-facing web interface for live session monitoring during system trials. All components are supported by a REST API service, and Firebase Firestore is used to store session data (all reactions with timestamps and anonymous user IDs) upon session termination. The web components were developed using React and deployed on Render as a static site. The watchOS application was built using SwiftUI and deployed using TestFlight. Finally, the API service was written using FastAPI and also deployed to Render.

### 3.1 Instructor-Facing watchOS Application

To use the system, the instructor first opens the Haptic-XCEL application on their Apple Watch and creates a new session, generating a random session ID. The instructor then communicates it to the students for entry into their web interface. As the students send reactions through the web interface, the instructor is able to view the reactions represented as emojis in the order they were sent. The reaction log is updated in real-time, with a unique haptic pattern playing alongside each type of reaction as soon as it is received. If multiple reactions of the same type are sent within a short period of time, they are grouped together and the corresponding haptic pattern plays only once.


(a) (b) (c) (d)

Fig. 1. Instructor-facing watchOS interface. (a) The instructor taps the *Begin Session* button on the home page. (b) The instructor views a confirmation message displaying the new session ID which is then dismissed. (c) The instructor views the live reaction log. The log contains emojis indicating the reactions that were sent by the students. The emojis are a hand emoji to indicate hand-raise and a crying emoji to indicate confusion. (d) The instructor taps *End Session* to end the session.

We opted to develop the instructor-facing side of the application on the Apple Watch due to its widespread adoption (with more than 100 million active users) and its vibro-tactile capabilities. While the Apple Watch features only a single "taptic" engine, Piateski and Jones found that intricate multi-actuator designs were ineffective when put under spatial limitations (such as the size of an Apple Watch), implying that pattern recognition tasks with small-sized target areas are better done with fewer vibro-tactile actuators [15]. Finally, the Apple Watch features a basic haptic library which, while not as customizable as the more advanced *CoreHaptics* library for iOS, is sufficient for this study.

To pick the haptic patterns, we relied on a big body of previous research in vibration pattern recognition and differentiation. Cholewiak and colleagues found that people are not significantly sensitive to frequency [2] thus making us deprioritize frequency when picking our haptics. On the other hand, strong vibrations and skin-squeezing sensations can help maximize differentiation [20], with bigger amplitude and longer duration being most effective at enabling faster pattern recognition [6]. Thus, the "Confused" and "Hand Raise" reactions enabled by Haptic-XCEL were assigned haptic patterns with strong vibrations as they are deemed more intrusive. On the other hand, the "Confident" reaction was assigned a pattern of short low-intensity vibrations, as this reaction is meant to be less intrusive.

### 3.2 Student-Facing Web Application

Students may access the web interface using any browser-compatible device. The students first enter a session ID provided to them by their instructor before being redirected to the second page with the three reaction options. When tapping on any of the reactions, the student's selection is confirmed by showing them a flying emoji animation of the corresponding reaction, and their reaction is transmitted directly to the instructor's Apple Watch. After tapping on a reaction, a 20-second cooldown begins, disabling that button for that duration to prevent spamming.

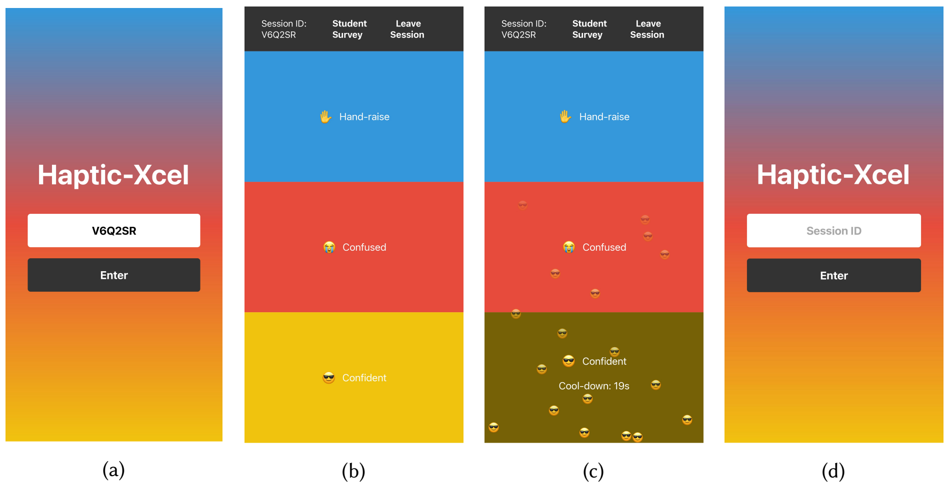


Fig. 2. Student-facing web interface. (a) Student enters a valid session ID in a textbox on the home page, after agreeing to the consent form and presses enter to proceed to the main interface. (b) Student sees three reaction buttons which fill up the screen. The first button is hand-raise, the second button is confused, and third button is confident. They are marked by blue, red, and yellow colors. (c) Student taps the *Confident* reaction, sending a stream of flying emojis corresponding to confident reaction (sunglasses emoji) to indicate that the desired reaction has been sent. (d) Student taps *Leave Session* in the top right corner to return to the home page.

## 4 METHODS

To measure the impact of facilitating real-time, low-friction feedback through visuo-haptic notifications, we ran a multi-stage, survey- and classroom-based study.

### 4.1 Pilot Study

As a baseline for comparison and to iron out system issues, we ran a pilot study in a large computer science lecture. The instructor commented that the system helped them feel more connected with the students, as he could tangibly observe their engagement. He also noted that the haptic patterns could be more intrusive and longer in duration in order to be noticeable. Based on this feedback, we extended the number of times the haptic patterns repeat to ensure that instructor has enough time to recognize and respond to the patterns.

### 4.2 Instructor Pre-Trial Survey

Before trialing the system, we surveyed 26 University instructors (9F, 17M) who taught a large lecture (> 60 students) during the Fall 2023 semester for a variety of subjects. We wanted to determine (1) the types of student feedback and reactions that instructors would find the most useful, (2) challenges when lecturing in-person, and (3) prior experiences with haptics. We found that the most desirable student reactions were *hand-raising for questions*, *confidence in understanding*, and *confusion*, which we implemented into the system. Other questions elicited a wide range of responses, giving us some background on the instructors recruited for the trials.

### 4.3 In-Class System Trials

We invited 6 of the instructors (2F, 4M) who participated in our pre-trial survey to use our system during one of their regularly-scheduled lectures, each lasting 50 or 80 minutes. As shown in Table 1, the recruited instructors covered a range of instructional methods, subjects, enrollment sizes, and student participation levels.

| Class | Course Type | Length | Students Present | Student User % | Instruction Method |
|---|---|---|---|---|---|
| C1 | First-year physical science course | 80 min | 43 | 40 | Writing on blackboard |
| C2 | Introductory social science course | 50 min | 200 | 21 | Writing on projected iPad |
| C3 | Introductory quantitative course | 80 min | 60 | 28 | Writing on blackboard |
| C4 | Introductory quantitative course | 80 min | 90 | 33 | Projected slides |
| C5 | First-year physical science course | 80 min | 50 | 21 | Writing on projected iPad |
| C6 | Intermediate life science course | 50 min | 70 | 46 | Projected slides |

Table 1. Summary of recruited classes for system trials.

The instructors did not know whether or not each student participated in our study, and the student participation was optional with no penalty to their grade in the course. At least two members of our research team were present for the duration of each study, troubleshooting any issues and writing down observations on how the system was used. The latter was not disclosed to the participants to eliminate bias. All data collected outside of the system-mediated data was recorded manually. We did not record any video or audio at any point. Before each lecture, we provided the instructor with the Apple Watch with the Haptic-XCEL application installed and taught the instructor the three haptic patterns. We demoed each pattern twice and asked the instructor to describe the patterns to encourage them to consciously think about what differentiates them. We then assessed their identification accuracy and recall by asking them to identify nine haptic patterns (each pattern repeated thrice).

### 4.4 Post-Trial Interviews and Surveys

After each trial, we verbally interviewed each instructor to assess their perception of the system. The transcripts were analyzed using a thematic analysis approach. We also sent a survey to all students in the participating classes. The survey asked students to (1) comment on their lecture experiences, (2) compare our system with other SRSs they have used in the past, and (3) assess how they believe the system influenced their instructor's behaviour, with most questions either being open-ended or on a 5-point Likert scale. Additionally, we sent the NASA TLX questionnaire to both students and instructors to assess the mental demand of our system, with each question on a scale from 1 (extremely low) to 10 (extremely high). While instructors were not compensated, all students who interacted with the system during class, completed the post-trial survey, and opted-in were entered in a raffle for a $10 Amazon gift card per class.

# 5 RESULTS AND DISCUSSION

## 5.1 In-Class System Trials

### 5.1.1 *Instructor Haptics Test*

Most instructors were able to quickly memorize and later recognize the three distinct haptic patterns and their associated reactions. However, instructor P4 was an outlier, as he was unable to remember or distinguish any of the patterns. Correspondingly, figure 3 shows the identification accuracy rates, both including and excluding the outlier.

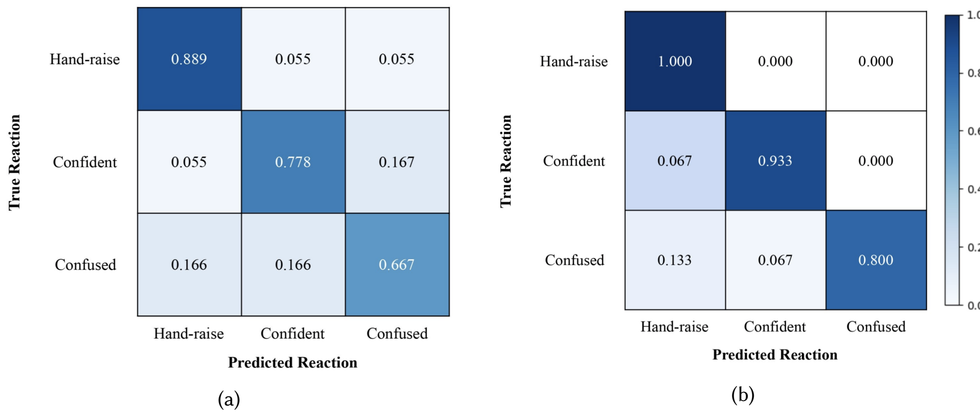


Fig. 3. Normalized confusion matrix for instructor haptics test. (a) Including instructor P4. (b) Excluding instructor P4.

All instructors excluding P4 always identified *Hand-raise* correctly. 4 of the 6 instructors commented that the patterns for *Hand-raise* and *Confused* were similar. Interestingly enough, instructors misinterpreted *Confused* as *Hand-raise* and *Confident* equally. Regardless, the instructors exhibited high retention and differentiation rates.

### 5.1.2 *Outlier: Class C4*

Despite being trained with the same procedure as all other instructors on the haptic patterns, instructor P4 was unable to recall, distinguish, or identify any of the 3 patterns. During the lecture, P4 did not engage with the watch in any way, despite students continuously sending reactions. In our debrief, the instructor lamented that the haptics were "distracting" and that if P4 looked at the watch, P4 would not have been able to organize what P4 wanted to say. The disconnect between instructor and the students was reflected in the student responses, all agreeing that the instructor did not use the system. From this trial, we conclude that the effectiveness of haptics is heavily dependent on the individual's sensitivity to sensory stimuli.

### 5.1.3 *Trolls and Spam Prevention*

In Class C2, we observed spamming or "troll" behavior where a small subset of students continuously sent reactions and thus used the system disproportionately. In particular, a single student accounted for 30% of all reactions in the class of 200 students with 42 active participants using our system. Consequently, we implemented a cooldown function, requiring users to wait 20 seconds before submitting another reaction. Even with this preventative measure, classes C3 and C5 still had a few students who consistently submitted reactions every 20 seconds, a behavior that likely does not align with natural engagement with class content.

## 5.2 Post-Trial Interviews and Surveys

### *5.2.1 Instructor Interview Themes*

***Direct awareness and bi-directional communication.*** Instructors noted that the haptics give them a sense of connection with the students. Instructors reported an increase in their awareness of the students' reactions, moving from traditional one-way communication to a bi-directional exchange. One instructor noted that the system *"made me more aware [of the students' engagement levels] and increased the connection between me and the students, which is usually a one-way thing"* [P6]. Another instructor shared a similar experience: *"I was discussing a concept they should already know, and the confidence reactions I received were mildly reassuring"* [P5].

***Real-time adjustment.*** Most instructors found that understanding students' confidence and confusion levels allowed them to adjust their lecture pacing in real-time. One instructor shared how he slowed down the lecture pace when he received confused reactions and sped up when he received confident reactions. Another instructor echoed this sentiment: *"Knowing [the students are] confident means I can move on and go faster"* [P3].

***Useful for first time instruction.*** Two instructors hypothesized that the system would be most effective for an instructor teaching a course for the first time, so that timely feedback could best help improve the teaching curriculum: *"if you're teaching a new class where you don't have the experience, I think the tool would be awesome… knowing what's confusing and what is not confusing is super valuable"* [P1].

***Visual versus haptic notifications.*** Instructors had mixed appreciation for the visual notification that accompanied the haptic patterns, though a majority found the visuals to be helpful, especially when they missed the haptic pattern. One instructor actually preferred haptics since *"the visual is hard, and I don't think I looked at the watch at all"* [P5].

### *5.2.2 Student Survey Results*

We received 62 valid student responses to our post-trial survey. Consistent with prior research [13], students who said they do not usually engage with their instructors during lecture cited not wanting to be a distraction, being shy, and general discomfort with asking questions in real-time. However, after using our system, about half of student responses cited an improvement in their learning experience. As one student put it, *"I was able to convey my confidence, confusion, and whether or not I had a question without having to actively say something out loud"* [S57].

50 of the students had experience with existing feedback systems, namely iClicker and Mentimeter. A paired, one-tailed student t-test revealed that compared to those systems, Haptic-XCEL was more low-friction and real-time, as students were able to more effectively and comfortably ask questions ($p < 0.005$, $p < 0.005$), convey their confusion ($p < 0.05$, $p < 0.005$), and express their confidence ($p < 0.05$, $p < 0.05$) with minimal delayed reaction from their instructor.

### *5.2.3 NASA TLX Questionnaire*

Students found our system less cognitively tasking than the instructors did. On a 10-point Likert scale, students rated the system to be neither mentally (2.4, $\sigma = 2.0$) nor physically demanding (1.9, $\sigma = 1.7$) to use. While instructors agreed that the system was not physically demanding (1.5, $\sigma = 0.8$), there was more disparity in the mental demand (4.3, $\sigma = 3.2$), likely due to the cognitive effort of lecturing while being aware of and trying to recognize the haptic patterns.

## 6 LIMITATIONS AND FUTURE WORK

Currently, there is limited literature on haptic pattern design for maximizing differentiability. More exploration is thus needed to determine the types of patterns that would be most clearly discernible and the best methods for defining an "N-dimentional haptic pattern set space" where N patterns are picked to be the most dissimilar from one another.

The system itself can improve in two ways. First, while we improved the system iteratively to be more robust to high traffic and trolls, spamming was still an issue in one of the later trials. Possible solutions include (1) limiting each unique user to a certain number of reactions per session or (2) rate-limiting and banning overly-active users after a warning. Second, the system could allow professors to pick their own reactions and associated haptic patterns, enabling better cognitive connection and subsequent recognition during system use.

Finally, more exploration on multi-modal interactions is needed. Specifically, integrating other types of wearables could improve accessibility of our system for users with varying degrees of physical, mental, and sensory capabilities.

## 7 ETHICS AND ACCESSIBILITY

### 7.1 Positionality Statement

As a team comprising of one graduate student and three undergraduate seniors in the computer science department, our engagement with this project is deeply rooted in our enthusiasm for and familiarity with technology. Our academic training and personal interests have largely revolved around leveraging technological solutions to address complex problems. Our enthusiasm for tech solutions may bias our interpretation of data towards positive outcomes. We recognize this potential bias in our perspective and commit to critically evaluating our findings.

### 7.2 Broader Impact Statement

The Haptic-XCEL system aims to enhance educational experiences by facilitating real-time, low-friction communication between students and instructors through visuo-vibrotactile modalities. This technology has the potential to positively impact learning environments by enabling instructors to quickly adapt to students' needs. However, the introduction of such technology also carries potential risks and unintended consequences. Reliance on technological feedback might inadvertently deprioritize the development of direct, interpersonal communication skills. In recognizing this, we aim to continuously evaluate and refine the system, ensuring that it aligns with the diverse needs within educational settings.

### 7.3 Accessibility Statement

The accessibility of our system was comparable to that of existing student response systems. However, to tailor our system to a broader audience of users with a range of various abilities, we would target different aspects of accessibility for the students versus instructors. While both the web and watchOS applications would benefit from features for the visually-impaired, we would leverage multimodal data representations for the instructors. As in the case of instructor P4, haptics can be inaccessible for people who are sensitive to stimuli, and in general, interacting with a smartwatch can carry friction for instructors who are not accustomed to wearing one. Thus, we could consider utilizing alternative data modalities including haptic, visual, or audio, via smart glasses, pin, or an earpiece.

## 8 CONCLUSION

As the number of modalities through which we can consume information expands, the classroom environments continue to evolve. Consequently, we identified an opportunity to build Haptic-XCEL, a novel student response system with integrated haptic feedback, enabling instructors to receive student feedback without the need for diverting their attention to a traditional visual interface. We conduced six in-class trials to evaluate our system as part of a multi-stage, survey- and classroom-based study. We found that Haptic-XCEL was more effective than other SRSs at facilitating reaction communication, improved student engagement, and heightened the instructors' understanding of their classroom.

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