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**ARTICLE**

# Assistive design for English phonetic tools (ADEPT) in language learning

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## Abstract

*Assistive Design for English Phonetic Tools (ADEPT) was developed to improve inclusion in classrooms and enhance collaboration among blind, low vision, and sighted learners of American English (AE) as a second/foreign language through better access to the International Phonetic Alphabet (IPA) symbols and the sounds they represent. Grounded in multisensory training efficacy, ADEPT involves auditory-visual-tactual integration through the use of visual-tactile IPA symbol cards and an auditory-visual companion website based on the Universal Design for Learning guidelines. Each card includes a symbol, description, and website reference number, all with braille notations. The website includes printed and audio-recorded information on the articulation of AE consonants and vowels, with recordings of each sound in isolation, syllables, and words. ADEPT's pedagogical efficacy was field tested with 21 blind/low vision adult L2 learners of AE (L1 Spanish), emphasizing vowel production in a pretest-training-posttest design, which had a training period of 10 weeks. Production scores from native-speaking raters were the dependent variable in a multilevel model with time (pretest-posttest comparison) as a fixed effect. Results showed a significant effect of time (i.e., improvement in production accuracy); the fit of the model improved when the random effect of participants was added ($p < .001$). In addition, pre- and post-study comments were very positive. ADEPT, which learners described as "invaluable," can facilitate a collaborative learning environment.*

***Keywords:*** *Assistive Technology, IPA Symbols, Phonetics, Pronunciation*

***Language(s) Learned in This Study:*** *English*

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## Introduction

Knowledge of phonetics (how speech sounds are produced, transmitted, and perceived) is critical to the general study of language, and more specifically, the development of phonological literacy among language learners and teachers (Hardison, 2014). Phonetic notation can serve as a component of pronunciation instruction to raise learners' awareness and noticing of second-language (L2) sounds in an effort to encourage output (Saito, 2013). As a metalanguage, it provides learners with the labels they can use to conceptualize speech (Mompean & Fouz-González, 2021), and a means for teachers and learners to communicate more precisely about L2 sounds (Couper, 2011). The International Phonetic Alphabet (IPA), which crosses linguistic and geographic boundaries, offers a one-to-one correspondence between sound and symbol, and makes salient the features that may be hidden in orthography such as the American English (AE) flap (e.g., medial consonant sound in "city"), frequently occurring processes that stem from connected speech (e.g., palatalization in pronouncing "miss you" [mɪʃju]), and differences among regional variants (e.g., "huge" [hjudʒ] or [judʒ]). Some teachers may look at the symbols as tools only for the teaching and learning of phonetics, per se, ignoring their pedagogical application (Baker, 2014); however, learners may see the symbols as a way to remember L2 sounds better (Mompean & Lintunen, 2015).

## Phonetic Tools for the Visually Impaired

To maximize the value of phonetic notation in language learning, there is a need for instructional materials that are accessible by learners who have visual impairments and may lack easy access to a resource for phonetic information. One of the strategies for the visually impaired summarized by Wells-Jensen (2005) was the use of IPA braille (Englebretson, 2009). Braille is a tactile writing system in which the alphabet, numbers, and so forth are constructed from six raised dots positioned in a grid of two parallel vertical lines of three dots each. From these dots, multiple configurations are created.

An online search for existing tools produced one set of tactile objects related to phonetics. Lillehaugen et al. (2014) developed a *Tactile IPA Magnet-Board System* for the teaching of phonetics and phonology to visually impaired students. Tactile magnetic classroom tools had been developed earlier for the learning of chemistry (Graybill et al., 2008). The Magnet-Board System consisted of phonetic and phonological rule symbols that were printed using a PIAF (Picture in a Flash) machine and adhered to a magnetic sheet, which was then cut into small pieces to accommodate each symbol (24 pt. font) to allow users to move the pieces around on a magnetic board. There were two main types of magnets: those with a tactile (i.e., raised) symbol, and those with a tactile braille notation for a symbol and a printed label (e.g., nasal). Although their system was not field tested, the authors suggested the development of similar tools for use in other fields including language instruction.

There is a caveat to the use of braille only. The National Federation of the Blind Jernigan Institute (2009) reported that less than 10 percent of the 1.3 million people who were legally blind in the United States in 2009 were braille readers. Similar downward trends were found for the United Kingdom where less than one percent of its two million visually impaired people as of 2012 used braille, and they tended to be people who had not been able to see from an early age (Rose, 2012). These statistics were attributed to several factors including a shortage of teachers and the advent of screen-reading software and smartphone apps. Screen readers have made the literacy process easier for the visually impaired; however, studies suggest that it is still advisable for the blind to learn braille (e.g., Orsini-Jones, 2009). Following the close monitoring of several college students during their foreign language studies at a university in the United Kingdom, Orsini-Jones recommended that blind students be encouraged to increase their braille literacy in both the first language and the foreign language being studied.

## Building a Supportive Learning Environment

Even if learners can read braille, using braille-only materials has a very isolating effect when others in the classroom setting can use visual materials and do not read braille (e.g., Arenas González, 2012; Donley, 2002). The learning support from collaboration in classroom group work enhances the motivation of all students to learn (Orsini-Jones et al., 2005). An additional source of support for visually impaired students is the virtual learning environment; for example, webpages can be accessed through the use of JAWS (Job Access with Speech) for Windows (Freedom Scientific, 2019), a popular screen reader which reads aloud information on the user's screen using synthesized speech. Orsini-Jones et al. reported virtual learning provided a successful experience for both blind and sighted students, although accessibility issues arose with some sites and databases. The authors concluded that "blind students suffer from information overload more than their peers as they can only process language via hearing…so they need to make an extra effort to compensate for the lack of sight" (2005, p. 152).

Encouraging a sense of belonging for all learners is an important element in community building. Communities, whether immediate and tangible or created through imagination (Kanno & Norton, 2003), have a strong impact on language learning by influencing motivation for learner agency and investment in learning (Pavlenko & Norton, 2007). The socioaffective profile of members of the disabled community can suffer if they perceive themselves distanced from the target language and its speakers because of limited access to knowledge and opportunities for skill development. They come to the learning task with their geopolitical, social, and personal histories shaped by power structures that, in the case of English, are frequently inequitable (UNESCO, 2020). In the past, in Latin America, and perhaps other regions, an

interest in learning English was not often fostered among people with disabilities; however, it has been increasingly encouraged as more are entering higher education (e.g., Cronquist & Fiszbein, 2017). Although English language proficiency can increase job opportunities for these learners, teaching materials have not kept pace, especially in terms of pronunciation. This is unfortunate because pronunciation is the skill that L2 learners often regard as the gateway to job and travel opportunities as well as intercultural communication (Low, 2021), and the one with which they struggle the most, particularly at the segmental level (e.g., Derwing & Rossiter, 2002). Attention to pronunciation form, especially involving instruction on the articulation of sounds combined with corrective feedback given during communicative activities, can improve segmental and suprasegmental pronunciation (e.g., Saito, 2013).

The goal of the current project was to develop tools that would address different input needs across a variety of language learners. Assistive Design for English Phonetic Tools (ADEPT) was created to facilitate the perception and production of sounds for nonsighted language learners through the use of tactile IPA symbol cards and a companion website.

## Multisensory Learning

ADEPT is based on the framework of multisensory (auditory, visual, and tactual[1]) learning. Both visual (e.g., Hardison & Pennington, 2021) and tactile input (Sparks et al., 1978) in conjunction with auditory input contribute to the perception of speech. If auditory-visual cues are congruent, perceptual identification accuracy may be enhanced; if cues are incongruent (e.g., /ga/-visual and /ba/-auditory), they may produce an auditory-visual perceptual illusion (e.g., /da/), a phenomenon known as the McGurk effect (McGurk & MacDonald, 1976). Similarly, manual tactile contact with a speaker's face when presented with incongruent auditory input can elicit an auditory-tactile illusory effect (Fowler & Dekle, 1991). Both phenomena support the multimodal nature of speech perception (e.g., Rosenblum, 2005). The perceptual outcome is the result of the identification and integration of cues (e.g., Hardison, 2012). For the visually impaired, manual tactile information from placing a hand on the face of a speaker–known as the Tadoma method (Alcorn, 1932)–enhances speech perception by at least 10% over auditory input alone (Gick et al., 2008; Sato et al., 2010), but is limited in its contextual appropriateness.

Research involving sighted participants shows that multisensory training protocols are more effective for human learning than those that depend on only one sensory modality (Shams & Seitz, 2008). In addition, L2 perception training often transfers to pronunciation improvement (see Hardison, 2021 for a research timeline). Individuals with visual impairments also benefit from multisensory training; specifically, hands-on experiences with learning objects paired with auditory information help them articulate their new knowledge and develop good strategies applicable to various educational contexts (Sensus ApS, n.d.). Therefore, to address the needs of both nonsighted and sighted learners, instructional materials should involve auditory, visual, and tactual perception.

Although sighted individuals may not appear to need tactile information, there is some evidence that input from this modality may offer a benefit. In a recent study involving visual and tactual perception, Fairhurst et al. (2018) asked sighted participants to determine whether the vertical bar in inverted T-shaped stimuli was shorter or longer than the horizontal bar in clear-cut and ambiguous cases. Vision provided a more accurate basis for perceptual judgments overall; however, while confidence ratings were higher based on vision for clear-cut cases, the sense of touch provided a higher level of confidence in ambiguous cases–a phenomenon the authors referred to as "fact checking by touch" (p. 1).

As part of its multisensory foundation, ADEPT followed Universal Design for Learning (UDL) guidelines (CAST, 2018), which advocate flexible learning environments to meet individual learner needs. Assistive technology is one of the pillars of the current project. Providing accessibility for low vision and blind learners in a way that is also usable by sighted individuals allows for collaboration in language learning contexts.

### Universal Design for Learning

Learners who need different kinds of support have often been marginalized (Rose et al., 2005). Although learners with disabilities now attend mainstream schools and can potentially receive the same quality of education, accommodations are necessary to create an effective learning process to help them reach their goals. From the perspective of language teaching, accommodations must address the fact that visual resources are frequently used and present a challenge for learners with visual impairments at all levels of education.

The UDL guidelines, defined in the Higher Education Opportunity Act of 2008 (U.S. Department of Education, 2008) as a "scientifically valid framework for guiding educational practice," attempts to improve the outcomes of all students by minimizing or eliminating learning barriers. It is a way to rethink education as an inclusive setting where everybody can learn together. To do that, UDL addresses three learning networks aligned with curriculum principles; that is, each area of the curriculum should provide multiple, varied, and flexible means of (a) *engagement* to optimize learner motivation, reflection, and strategy use (*affective* network, "the WHY of learning"), (b) *representation* to customize the presentation of information, including alternatives to visual information (*recognition* network, "the WHAT of learning"), and (c) *action and expression* to facilitate access to tools and assistive technologies (*strategic* network, "the HOW of learning") (CAST, 2018; Rose et al., 2005). Important curricular components include (a) goals (e.g., learning expectations), (b) methods (e.g., flexible strategies to support learning), (c) materials (e.g., media options), and (d) assessment to measure learner knowledge, skills, and engagement.

## Study Objectives

The current study had three main objectives. The first was to develop tactile materials to help visually impaired learners of English to learn the metalanguage of IPA symbols and practice the sounds they represent. These materials were designed to be reproducible as inexpensively as possible in various educational contexts, and to be appropriate for collaborative learning between sighted and nonsighted users. The second objective was to create an accessible companion website. By putting these tools together, ADEPT was created following UDL guidelines. The third objective was to field test the pedagogical efficacy of this multisensory input with a visually impaired population. A pretest-training-posttest design assessed the impact of training on English pronunciation by adult low vision and blind Spanish-speaking learners. Their feedback on the materials was also requested before proceeding to the project's final stage of 3D printing the symbol cards using plastic filament.

## Method

### Participants

Participants were 21 visually impaired adult native speakers of Spanish living in a Latin American country who were recruited through an announcement on social media. Those who volunteered to participate completed an online survey in Spanish and an interview via email about their language learning backgrounds, computer skills, previous strategies for learning L2 English, and goals for L2 learning. See Table 1 for a summary of participant information.

It is noteworthy that no participant reported a successful English learning experience. In the following quote translated from Spanish, one participant commented on the general lack of suitable instructional materials. This quote also underscores the fragility of the learner's motivation.

> …the majority of activities in textbooks required associating images with text, and I could not do it. I remember I was good in pronunciation and I had a good memory to learn English in elementary school and even until the 8th grade. But one day, the teacher started teaching songs and I could not read the lyrics on the paper so I lost my interest in learning.

**Table 1**

*Participant Information*

| | **Number of Participants in Parentheses (*N* = 21)** |
|---|---|
| Vision Status | Legally blind (17); Low vision (4) |
| Age Range | 18–35 years (17); 35–50 years (2); older than 50 (2) |
| Highest Education Level | Secondary school (6); technical school (8); professional training (5); undergraduate studies (2) |
| English Learning Background (beyond secondary school) | During technical studies (4); at university (7); took an informal English course (8) |
| Assistive Technology Knowledge | Familiar with screen reader JAWS (19); used ZoomText (e-magnifier/reader) (2 with low vision) |
| Previous Strategies for Learning English | Listening to song lyrics and audiobooks; using videos (low vision participants); Duolingo to study grammar |
| Goals for Learning English | Improve professional profile and job opportunities; intercultural communication; travel; enjoyment in learning languages |

The participants' biggest challenges among the language skills involved pronunciation and auditory identification of sounds. They were comfortable with their knowledge of English grammar and general vocabulary but wanted to improve their pronunciation. Their phonetic knowledge was limited and there were few opportunities to practice speaking. The availability of interaction in this study with other learners and an experienced teacher appealed to them as a way to facilitate acquisition. The project's announcement also sounded innovative. All participants wanted to demonstrate their ability to learn with accessible materials and felt the inclusive nature of the class was an advantage. They also reported very positive attitudes toward American culture so they were interested to learn more about American English. Knowledge of English offers many opportunities to the community of low vision and blind individuals. These participants did not consider their disability to be a limitation in reaching their goals. In terms of oral English proficiency, an experienced English teacher assessed the learners to be at either the A2 or B1 levels according to the Common European Framework of Reference (Council of Europe, 2001).

The researchers determined that there was no appropriate control group for this population; however, the situation was accepted given several factors: (a) the focus of the study was to field test ADEPT, (b) there were no English interaction opportunities for the participants outside of the training sessions during the study period, (c) the occurrence of a test effect was highly unlikely since the pretest was conducted at the beginning of Week 2 and the posttest was in Week 10, and (d) the test content was not part of the training sessions nor accessible to participants between the test sessions.

## Materials

### *Pronunciation Pretest and Posttest*

Although both consonants and vowels were addressed in the study, because of time constraints, the training focused more on vowels in American English (AE) to address the participants' needs and interests; AE vowels were more challenging than consonants for them. Therefore, the testing stimuli also focused on vowels and consisted of several exemplars of each AE vowel sound in frequently occurring words in short

sentences adapted from *English Pronunciation Made Simple* (Dale & Poms, 2005). As shown in Table 2, there were 50 vowel tokens across 16 sentences.

**Table 2**

*Sentences Used in the Pronunciation Pretest and Posttest*

| Sentences (target vowel sound is underlined) | Target Vowel |
|---|---|
| 1. Peas and beans are good to eat. | [i] |
| 2. Tim's sister swims a little. | [ɪ] |
| 3. Ten times seven is seventy. | [ɛ] |
| 4. Many animals inhabit Africa. | [æ] |
| 5. Doctors say jogging is good for the body. | [ɑ] |
| 6. Sue flew to the moon. | [u] |
| 7. This is a good cookbook. | [ʊ] |
| 8. The southern governor is Republican. | [ʌ] |
| 9. The author gave a long talk. | [ɔ] |
| 10. Nurses do worthy work. | Rhotacized vowels: [ɝ] (stressed syllable), [ɚ] (unstressed) |
| 11. Labor Day is in the first week of September. | |
| 12. Maine is a great state. | [eɪ] |
| 13. The North Pole is close to the Arctic Ocean. | [oʊ] |
| 14. Owls are now found throughout the world. | [aʊ] |
| 15. My sister has a wild life. | [aɪ] |
| 16. The auto industry is a loyal employer in Detroit. | [ɔɪ] |

*Note.* Sentences were adapted from *English Pronunciation Made Simple* (Dale & Poms, 2005). IPA symbol use follows Ladefoged's guidelines (e.g., Ladefoged & Disner, 2012).

### *Development of Tactile IPA Symbol Cards*

The *Tactile IPA Magnet-Board System* (Lillehaugen et al., 2014) was borrowed through interlibrary loan and reviewed by a blind, experienced teacher of English who was familiar with phonetics. The following modifications were recommended for the design of each IPA symbol card to be produced in the current study: (a) an increase in size to make it easier to manipulate, (b) inclusion of important information with the symbol to facilitate learning and memory recall, and (c) addition of a reference number to guide users to a companion website for audio recordings and information on the sounds. Based on these ideas, several prototypes were developed and evaluated by the researchers until a final decision was reached. Braille notation was included on the cards following recommendations in the literature (e.g., Englebretson, 2009; Orsini-Jones, 2009; Silverman & Bell, 2018) and to accommodate a range of learner backgrounds, ages, learning styles, and educational contexts.

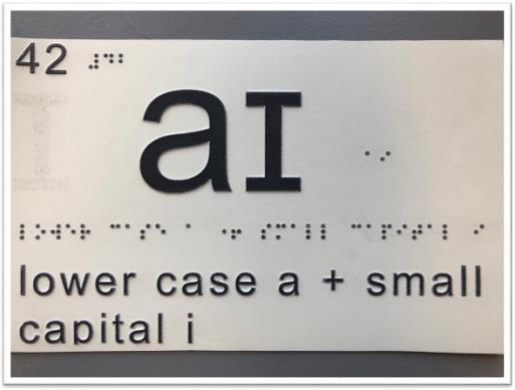
Each card included an IPA symbol for an AE consonant or vowel sound (see Appendix A) following Ladefoged's guidelines (e.g., Ladefoged & Disner, 2012). The sounds represented the AE phonemic inventory although additional cards were created based on the difficulties that some frequently occurring sounds present for many L2 learners. These additional sounds included each voiceless aspirated stop (e.g., the initial sound in "pet," "top," "catch") and the flap (e.g., the medial consonant sound in "city"). Cards were also prepared for the stressed and unstressed rhotacized (r-colored) vowels (e.g., "bird," "teacher") and each diphthong (a single vowel with continuously changing quality) (e.g., "buy," "loud," "boy").

Following Ladefoged's transcription (e.g., Ladefoged & Disner, 2012), the mid front and mid back vowels were treated as diphthongs (i.e., [eɪ] "day" and [oʊ] "low").

Four sets of 45 tactile IPA symbol cards were prepared for field testing. To create each card, a file was made in MS Word using Doulos SIL phonetic fonts and the Duxbury Braille Translator (Duxbury Systems Inc., 2019). A Canon imageRUNNER ADVANCE 4245 copier printed the image on swell (thermal) paper. This was fed through a tactile image enhancer (by Reprotronics) to produce a raised image (Figure 1), which was applied to a magnetic adhesive sheet (by Magicfly) to allow users to move symbols on a surface in order to transcribe words and keep each card in place.

**Figure 1**

*Sample Tactile IPA Symbol Card for Diphthong* [aɪ] *Produced on Swell/Thermal Paper*




As shown in Figure 1, in the upper left corner of each card, a reference number was printed as a tactile numerical character (48 pt. font) along with its braille notation. This number referred the user to additional information on the companion website. The tactile IPA symbol (220 pt. font) was centrally located with its corresponding notation in braille to the right. Below the symbol was the braille for the typographical description of the symbol (Pullum & Ladusaw, 1996), which then appeared in standard orthography (48 pt. font) below that. The information on each of these cards was accessible to both sighted and nonsighted users for collaborative learning.

### *Companion Website*

A companion website was developed to be used in conjunction with the IPA symbol cards although the site can be used independently as well. It was organized according to (a) the need for a user-friendly design, (b) input from various test users involved with language teaching and assistive technology, and (c) the principles of Web Content Accessibility Guidelines (WCAG) 2.1 (Accessibility Guidelines Working Group, 2018). The site includes (a) the names of the phonetic symbols that represent AE sounds, (b) the typographical description of the symbols, (c) information on how the sounds are produced with reference to the descriptive characteristics for consonants (e.g., place and manner of articulation, voicing) and vowels (e.g., height, backness, rounding), and (d) recordings of each sound in isolation, syllables, and frequently occurring words. The site also includes specific technical details for the production of the symbol cards.

## Procedure

As stated earlier, the goals were to create the tools, test their use by language learners, and elicit the learners' perceptions of their efficacy and any recommendations for their future use before the final 3D printing of the cards. Following a pronunciation pretest, there was a 10-week instructional period, pronunciation posttest, post-instruction interview (see Appendix B), and post-study email comments from the participants regarding the materials and instruction.

Participants gathered at a large university where they were acquainted with the goals of the study, the

technical equipment, and the informed consent procedure, which was read to them by JAWS. This was followed by the pronunciation pretest, which was administered using the delayed repetition technique (Flege et al., 1995) as demonstrated in Excerpt 1 for the target vowel [i]:

**Excerpt 1**

*Delayed Repetition Technique*

> Recorded Native Speaker Voice #1: Peas and beans are good to eat.
>
> Recorded Native Speaker Voice #2: What is good to eat?
>
> Participant repeats what Voice #1 said: Peas and beans are good to eat.

This technique allows control of the content of each participant's production but reduces imitation. Precise recall of the content is not necessary as long as sufficient exemplars of the target sound are produced. Other elicitation options such as a picture prompt or the use of braille were not appropriate for the population. Most of the participants were blind, and only half of them were braille literate. Their pretest and posttest responses were audio recorded for later analysis.

### *Instruction*

Following the pretest, instruction using the tactile IPA symbol cards and website spanned 10 weeks. Each participant was given access to a computer with JAWS (2019) for Windows and a Wi-Fi connection. Alternatives for producing IPA symbols on the computer included the installation of IPA (SIL) + Keyman Desktop, which installs the IPA keyboard on the computer, and entering IPA symbol Unicode characters with the conventional keyboard. To enable JAWS to read or describe IPA symbols, a dictionary of the symbols and Unicode characters must be installed in the JAWS SBL file (instructions are available on the companion website and from http://www.ruf.rice.edu/~reng/jaws-ipa.html).[2] Training sessions took about three hours per week and included an overview of articulatory phonetics. Participants practiced perception and production while they worked with the cards and website. The focus of each week's instruction is outlined in Table 3. At the end of the 10-week period, a pronunciation posttest was conducted using the same stimuli as the pretest. Through interviews and a follow-up email, participants provided feedback on the instructional activities, IPA symbol cards, and the website. Each participant was compensated the equivalent of $28 in U.S. dollars.

**Table 3**

*Summary of Weekly Instructional Activities*

| Week | Activities |
|---|---|
| 1 | • Introduction to the goals and general outline of the study<br>• Installation of technical adjustments to the university computers<br>• Review of informed consent procedure |
| 2 | • Administration of the pronunciation pretest using the delayed repetition technique<br>• Explanation of the most relevant concepts in phonetics |
| 3 | • Exploration of the companion website<br>• Practice in perception and production of consonant sounds |
| 4 | • Organization of class into 4 small groups. Each group worked with a set of IPA symbol cards and a leader who could read braille. |
| 5 | • Practice in perception and production of vowel sounds<br>• Practice in manual creation of IPA symbols by participants using pipe cleaners.<br>• Typing IPA symbols using Unicode characters |
| 6 | • Focus on vowel production and practice typing IPA symbols on the computer |
| 7 | • More practice involving vowel production<br>• Using the Color Vowel Chart (Taylor & Thompson, 2012, as cited in American English, 2020) to practice vowel sounds (e.g., “green tea,” “blue moon”)<br>• Continued use of the companion website with the IPA symbol cards |
| 8 | • Continued vowel practice using the Color Vowel Chart and typing IPA symbols |
| 9 | • More practice with the website and the IPA symbol cards, especially the vowels |
| 10 | • Administration of the pronunciation posttest<br>• Feedback from the participants<br>• Compensation offered to the participants<br>• Follow-up email |

## Results and Discussion

### Pronunciation Ratings

Three native speakers of English rated the participants’ pretest and posttest audio recordings. Each rater was from the upper Midwestern region of the United States and had several years of experience teaching English as a second and foreign language. They were given access to a password-protected website where the audio files had been uploaded. The pretest and posttest recorded samples were randomized. Raters were given a copy of the target sentences and were instructed to rate the pronunciation accuracy of only the underlined target vowel sounds. One point was given for a vowel identified as the target. For example, if one of the sentences had been “The dog bit [ɪ] the boy,” and the speaker had produced the underlined vowel as [i] resulting in “The dog beat the boy,” no point would have been given. Raters were told that mispronunciations would not always constitute minimal pairs (e.g., “bit,” “beat”). Raters completed a score sheet for each audio file and submitted their score sheets to a folder on the site. They were compensated $12.50 in U.S. dollars per hour.

## Data Analysis

Of the 21 participants in the study, data from four had to be omitted from analysis because of their failure to follow task instructions or to make a sufficient number of attempts during the pretest recordings. The number of target vowel sounds attempted by each of the remaining 17 participants was satisfactory and used as the number of possible points for a given sentence. Participants were not penalized for failing to produce a specific target because it could have been due to reasons other than production ability such as nervousness or limitations in memory recall.

For each participant's production of a sentence, the three raters gave 1 point for a vowel accurately produced and 0 for one that wasn't. Of the 16 sentences, 15 had three occurrences each of a target vowel; the remaining sentence had four. This approach yielded a score per vowel from each rater. Rater judgments were evaluated for inter-rater reliability using intraclass correlation coefficient (two-way mixed-effects model with average measure reliability). Cronbach's alpha was high at .98.

Given that the raters' assessments were reliable, their scores for each vowel were averaged so that a percentage could be calculated to reflect the accuracy of each learner's production relative to the number of attempts that were made. As noted above, this approach recognizes that failure to produce a word could have stemmed from memory limitations; in fact, this was verbalized by some participants, especially in the pretest when a few tended to be a little nervous.

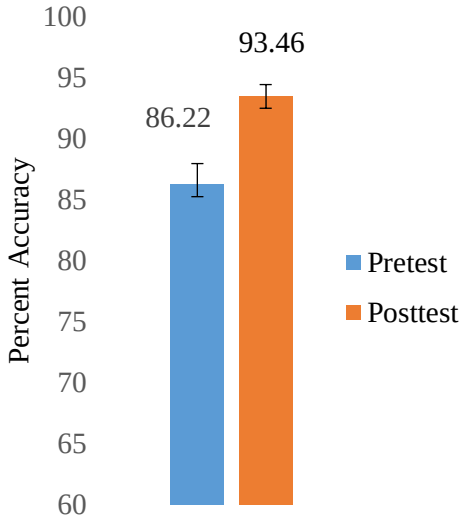
In a few cases, a participant could not recall a specific word but used one of similar meaning. The substitution was included in the analysis if the word contained the target vowel. For example, substitution of the word "job" for "work" was not included but use of "around" for "throughout" in the phrase "throughout the world" and use of "government" instead of "governor" were included. These types of substitutions suggested that some participants were focused more on meaning than form during the task.

## Effects of Training

A Shapiro-Wilk test indicated no violations of normality in the data, $W(17) = .962$, $p = .669$ for the pretest, and $W(17) = .950$, $p = .451$ for the posttest. As shown in Figure 2, the pretest mean percent accuracy was 86.22, $SD = 7.06$, 95% CI [82.60, 89.85], and rose to 93.46, $SD = 3.87$, 95% CI [91.47, 95.45].

**Figure 2**

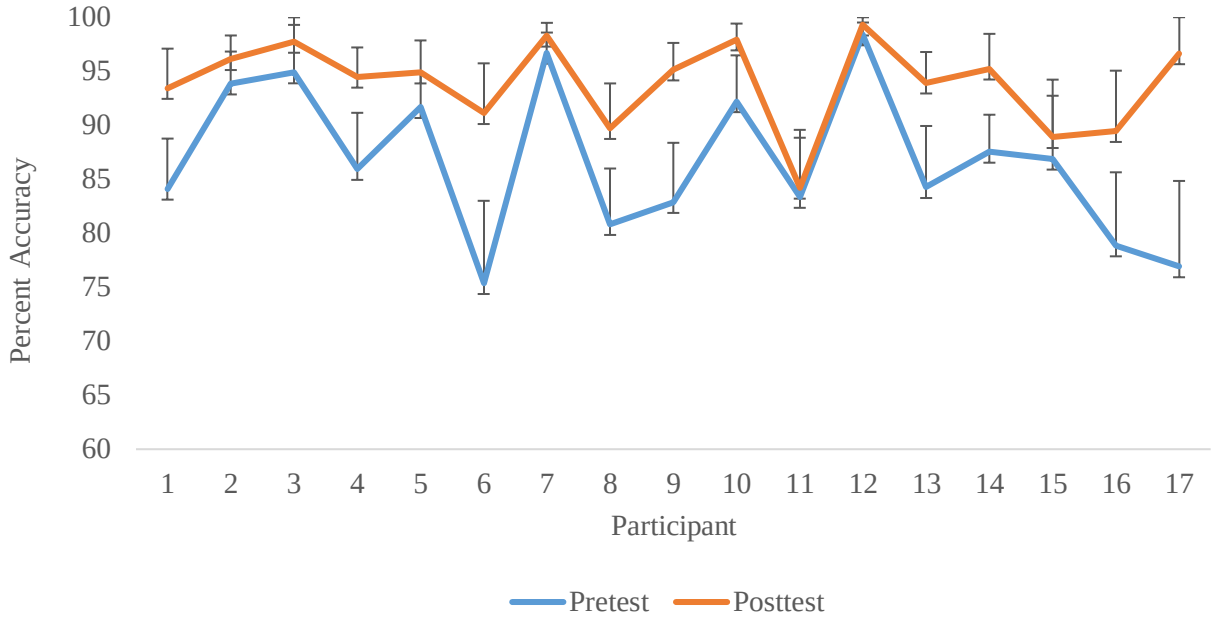
*Group Mean Percent Accuracy (with Standard Error Bars) for L2 English Vowel Production*



As shown in Figure 3, mean percent accuracy increased, and standard errors decreased in participants' vowel production following training.

**Figure 3**

*L2 English Vowel Production Per Participant: Pretest and Posttest Accuracy (with Standard Error Bars) as a Percentage of Attempts*




The structure of the data in this study was hierarchical with the variable of time (1: pretest, 2: posttest) nested within the participants. Each learner's percentage score was entered as the dependent variable in a multilevel linear model (also known as a linear mixed model) for analysis. An initial basic model was constructed in which all parameters were fixed to provide a baseline for comparison with subsequent models. The maximum likelihood estimation method was used. Results indicated a significant effect of time on vowel production accuracy, $F(1, 34) = 14.405$, $p = .001$. Participants were then incorporated into the model as a random effect. The covariance type *unstructured* was selected to estimate the covariance between random slopes and intercepts. Following Field (2018), the change in *-2LL* (i.e., log-likelihood, a measure of error or unexplained variation) from the previous model was used to assess improvement in the fit of the final model. In the final model, the relationship between training and vowel production accuracy showed significant variance in intercepts across participants, $\text{Var}(u_{0j}) = 55.510$, and the slopes and intercepts negatively and significantly covaried, $\text{Cov}(u_{0j}, u_{1j}) = -17.562$. Participants with a higher intercept tended to have a lower slope, accounting for the negative correlation between the random intercept effect and the random slope effect. Including this variability across participants significantly improved the fit of the model, $\chi^2(df = 3) = 11.34$, $p < .01$, which demonstrated an increase in learners' vowel production accuracy following training. By allowing the intercepts to vary across the participants, the effect of time (i.e., the pretest-posttest comparison) increased, $F(1, 21.415) = 35.999$, $p < .001$, with a final *b*-value of 7.166 ($SE = 1.194$, 95% CI = 4.685, 9.647).

All participants showed improvement in vowel production to varying degrees. The most problematic target vowel across participants was [ɪ]; for example, in the sentence "Tim's sister swims a little," some pronounced the vowel in "sister" as [i] (vs. [ɪ]) although production of the target vowel, especially in the posttest, was more accurate in the other words in the sentence.

## Instructor Notes

After each training session, the instructor, who is blind and has English teaching experience, wrote down her impressions and the role that ADEPT could play in other English language classrooms. Some of the instructor's notes are presented here using the UDL framework for analysis.

All participants were curious about this learning experience; the idea of making something different or learning beyond the traditional outcomes was attractive for them. At the end of the first day, the instructor wrote,

> Maybe the hardest point that day was to explain to them the difference between a traditional English course and this project creating a tool to teach phonetics. I remember that two individuals were reluctant at first because they believed they needed prior knowledge. They were afraid of phonetics, and I am sure that others were, too. The majority of them had ignored the phonetic component of the English language because teachers usually taught grammar and vocabulary. As a result, it sounded new and interesting, too. The most suitable word is innovative.

The following three situations that occurred during the training period exemplify the positive effect of using ADEPT. In Session 4, after learners had begun to work with the IPA symbol cards, they created the same symbols using pipe cleaners to demonstrate their knowledge of the form. In doing so, they designed their own material. When blind people create a figure by touching another one, they understand the shape better (Sensus ApS, n.d.).

From the above notes, the three UDL principles are evident as follows:

- **Engagement**: From the beginning, participants were interested in learning the symbols' shapes and modeling them with pipe cleaners. Despite variations in manual dexterity, they were always willing to participate. (Affective network)
- **Representation**: Learners could identify the tactile information on the symbol cards without difficulty, by recognizing the shape of the figure and, in some cases, reading the braille notation. (Recognition network)
- **Action and Expression**: Learners created their own phonetic symbols using pipe cleaners by using the symbol cards as models and touching other classmates' work (Strategic network).

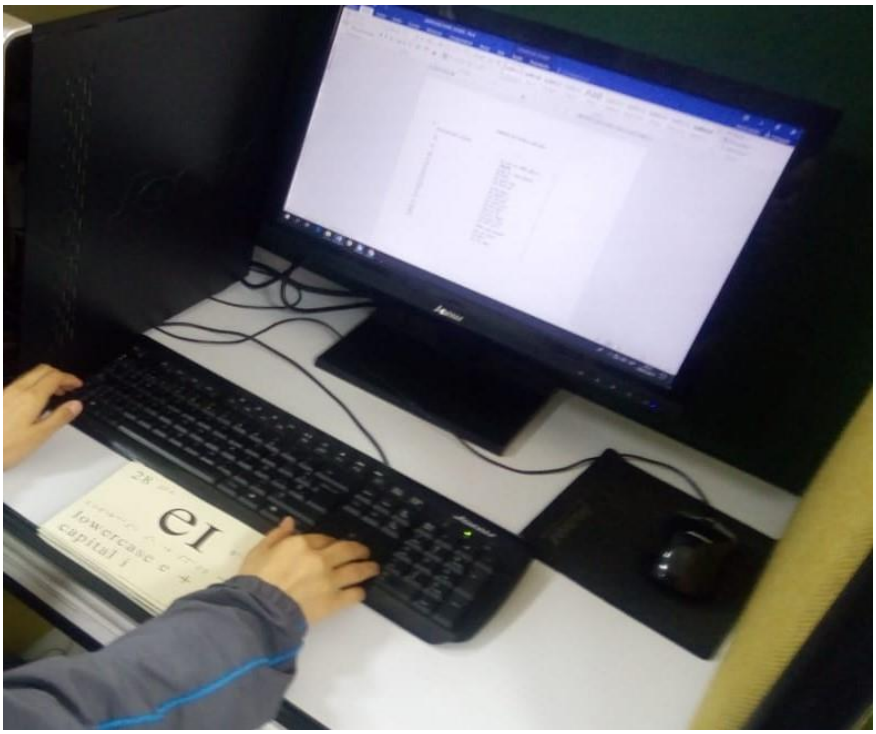
Another situation that demonstrated the positive effect of the training was in Session 6. Before finishing the session, learners were able to use the Unicode characters to type phonetic symbols on the computers. A little confusion occurred with the diphthongs and some of the consonants that required the participants to enter two characters (e.g., the voiceless aspirated bilabial stop [$p^h$]).

The UDL framework can be applied to the above session also:

- **Engagement**: Some learners had a little difficulty using the computers; however, most of them could type many words phonetically. Some opted to type the Unicode characters next to the word to demonstrate their abilities. (Affective network)
- **Representation**: With the aforementioned adjustments made to JAWS, learners were able to search for the Unicode IPA fonts to type the corresponding phonetic symbols. (Recognition network)
- **Action and Expression**: Learners were able to memorize the four characters in each symbol's Unicode and could type the symbols using the conventional keyboard and understand the shape of the characters on the screen because of sufficient prior contact with them on the symbol cards (see Figure 4). (Strategic network)

**Figure 4**

*Participant Working Individually with IPA Symbol Cards and Companion Website*




The final example of the positive effects of using ADEPT occurred in Session 7 when the Vowel Color Chart (Taylor & Thompson, 2012, as cited in American English, 2020) was introduced. Although the majority of the learners had never seen color, the chart associated many common nouns with a color adjective having the same vowel sound (e.g., gr<u>ee</u>n t<u>ea</u>). Each group, made up of four or five learners, worked with a set of IPA symbol cards (see Figure 5). When they disagreed on the adjective, they worked together to compare sounds among word options. The UDL framework can also be applied here:

- **Engagement**: Learners always showed a high level of motivation and excitement in terms of pronouncing, listening, and repeating in order to find the correct vowel for an adjective-noun pair. (Affective network)
- **Representation**: Learners could listen to an audio file to compare the vowel sounds in the different names of the colors and the nouns they modified. They could also use the screen reader to read the chart with English sounds. (Recognition network)
- **Action and Expression**: The importance of interaction was evident when the students worked together to find similarities between elements in the input. Their ability to use terminology to discuss an English word's pronunciation was an accomplishment. (Strategy network)

**Figure 5**

*Participants Working in a Group with IPA Symbol Cards and the Companion Website*

## Post-Instruction Interview

In the post-instruction interview, the questions were related to self-reflection on each participant's (a) improvements in listening and speaking skills, (b) new strategies to practice English, and (c) general perceptions of the course and materials.

In terms of listening skill development, learners reported the importance of the following developments over the training period. They:

- understood the phonetic terminology describing consonants and vowels;
- became aware that a letter or letters with the same spelling could have different ways of being pronounced;
- recognized that this was an ongoing learning process; and
- comprehended words when they were produced slowly (but experienced difficulties when a speaker spoke quickly).

In general, perceptions about the training were positive. All participants affirmed that they had improved their listening skills although they reported that they should practice more. In terms of speaking skill development, the learners reported the following accomplishments. They:

- developed more awareness of the position of the tongue, lips, and jaw when producing a sound;
- recognized the necessity for more practice; and
- found that repeating the same sentence many times helped to produce the sound correctly.

Although participants were pleased with their accomplishments, they wanted to feel more confident in their speech production, and planned to adopt the following strategies to continue to develop their speaking skills:

- Continue to use the course materials.
- Pay more attention to songs and radio interviews.
- Listen to a song many times and repeat the lyrics.
- Listen to international broadcasts and audio recordings on the Internet.
- Try to practice interacting with people who could speak English.

The majority of students said they were planning to continue to develop their skills using diverse materials, including the website for this project.

### *Learner Comments on the Training*

All of the learners indicated that the instruction was helpful and clear. They:

- expressed an interest in a longer course so they could practice more.
- found the activities were helpful to understand the differences among vowels, including monophthongs and diphthongs.
- mentioned the value of a separate course for more advanced learners.

They requested creation of the same accessible scripts for other screen readers such as NonVisual Desktop Access, a free open-source screen reader developed by NV Access.

### *Learner Comments on the Website*

Learners made positive comments about the website and clarity of the audio files. Additionally, they:

- suggested changing the colors on the website for low vision users.
- requested the addition of some games related to phonetics and more audio files with minimal pairs.

### *Learner Comments on the IPA Symbol Cards*

With regard to the symbol cards, learners offered positive comments and made the following suggestions:

- A second set of cards in a smaller size might allow users to join the pieces and form words like a puzzle.
- A "higher size" (greater tactual enhancement) for the braille might be helpful for people with diabetes.[3]

In general, the participants enjoyed using these tactile cards to learn the phonetic symbols and understand the articulation of sounds. Some of their suggestions were implemented in the final stage described below.

## Development of 3D Printed Cards

Although the IPA symbol cards used in the study were successful, paper deteriorates from use over time. In the interests of sustainability and to address some of the issues raised by participants in their post-study feedback, the next stage in this project was to 3D print the IPA symbol cards using plastic filament (Jaquiss, 2012).

Figure 6 and Figure 7 show the process of printing one of the symbol cards (each 5 in. by 8 in.) and the final product. Two contrasting colors were used to enhance perception for low vision users. The braille dots were raised more compared to the swell paper version for tactual enhancement; however, the card's content and its organization were the same. A small magnet could be adhered to the back of each card for use on a magnetic surface to avoid accidental displacement but still permit the user to move it around to transcribe words. In areas where 3D printing may not be available, a sign shop might be, which would increase availability of the symbol cards and reduce cost.[4] Two sign shops in the US produced a sample IPA symbol

card (see Figure 8) using the STL files that were developed in the current study.

**Figure 6**

*3D Printer Production of the IPA Symbol Card for Aspirated /p/*

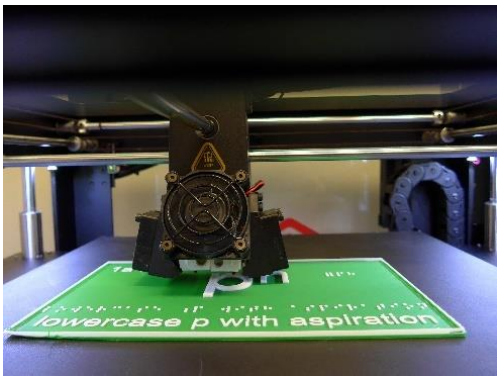



**Figure 7**

*Symbol Card for Aspirated /p/ Produced by a 3D Printer*

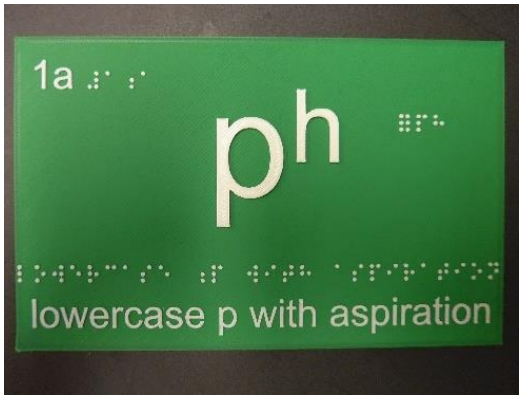



**Figure 8**

*Symbol Card for Aspirated /t/ Produced by a Sign Shop*

## General Discussion

The current study involved the creation and testing of ADEPT (Assistive Design for English Phonetic Tools) consisting of tactile IPA symbol cards and a companion website. The combination of these materials allowed low vision and blind Spanish-speaking L2 learners of English to improve their understanding of the articulation of English sounds and the instructor's feedback on their pronunciation. The quantitative and qualitative outcomes following a 10-week training period revealed increased phonetic awareness and significant improvement in the learners' pronunciation of vowels, the most problematic AE sounds for them. Feedback on the program and tools, including the website, was very positive.

The project was implemented following the guidelines of the Universal Design for Learning. The Affective network, related to learner engagement, emerged through interaction among learners, who developed a sense of community within and across the groups in which they participated throughout the training. The Recognition network was addressed through the multimodal materials (i.e., the symbol cards and website). Learners could feel the IPA symbols, reproduce them manually with pipe cleaners, and use them in conjunction with auditory information from the instructor, other learners, and the website to practice their new perception and production skills. The Strategic network was evident through learners' access to information that was optimized through assistive technology and multiple activities during the 10-week training period.

During the instructional activities, participants worked in groups of four or five. Each group worked with a set of IPA symbol cards, and each learner had access to a computer to practice typing the symbols and using the website. Some participants were designated as leaders in their corresponding groups. Leaders were the most skilled learners in terms of digital literacy, braille use, and previous experience with English, so they were able to establish a supportive community for the other group members. This was a good example of a collaborative learning environment in a language classroom, allowing learners to reach their full potential.

The learners' identities as non-native English speakers played an important role with regard to their motivation to participate in the study. Their desire to have better professional opportunities, better contact with people from other cultures, and better comprehension to enhance enjoyment of music and movies were important factors that allowed them to engage fully with the learning process and demonstrate improvement in their abilities following training.

Some limitations arose in the study. The first involved time constraints. The participants would have liked more time to practice with the IPA symbol cards. They also expressed a desire for opportunities to practice speaking English on a regular basis, which is often a challenge in areas where it is not spoken in daily life. The second involved challenges in creating materials that could be duplicated in other learning contexts. Although the website provides information on the creation of the symbol cards used in the study, paper will deteriorate from use over time. For that reason, 3D printing with plastic filament was a solution, but it is a more costly option, and these printers are currently less widely available. A less expensive and more available option is a sign shop. The third limitation was the lack of a control group, although this was not considered problematic for several reasons: (a) the project goal was to field test ADEPT, (b) the learners lacked English interaction outside of the training sessions during the 10-week period, and (c) a test effect was highly unlikely given the span of eight weeks between pretest and posttest. The fourth limitation involved a technical issue. Scripts were created and temporarily installed in the software JAWS for Windows to enable the software to navigate the website easily and allow it to read the names of the IPA symbols. Unfortunately, they disappeared when software updates occurred, requiring them to be reinstalled.

## Conclusion

With good materials and instructional methods that create an inclusive classroom, disabilities are not obstacles to language learning. Multisensory input (auditory, visual, tactual) enriches language acquisition, as do cooperative learning environments and learner empowerment by giving them a true sense of the

communicative purpose of learning another language. Importantly, the learners in the current study were able to participate in an empowering process through the training. Their comments and reflections suggested that they not only had the opportunity to learn about phonetics and improve their English pronunciation, but also became aware that they could discover other types of knowledge through curricular accommodation, including assistive technology. Their active participation and strong enthusiasm throughout the study were evidence of their eagerness to learn.

Language teachers everywhere can encourage the relevance of phonetic study to improve oral skills in any language, as well as the importance of cooperative learning to create a truly inclusive environment. The accessible materials and pedagogical activities were key elements for reaching the goal of greater engagement in learning. ADEPT can innovate the classrooms of the world.

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## Notes

1. Tactual refers to the sense of touch; tactile refers to something tangible or perceptible.
2. On the companion website, there is also a downloadable file with the braille notations for the IPA symbols. This manual is authorized and made available by the International Council on English Braille. Also included on the companion site are instructions for creating the symbol cards using swell/thermal paper.
3. Individuals with diabetic neuropathy may experience difficulty reading braille. Some are unable to perceive the individual points clearly (e.g., Heinrichs & Moorhouse, 1969).
4. The estimated cost for a set of 45 IPA symbol cards produced by a sign shop was less than $1,000 in U.S. dollars when the sample in Figure 8 was produced. For comparison, the cost of producing 5 sets (each 45 symbol cards) using the swell/thermal paper approach was less than $400 in U.S. dollars including the paper, ink, and magnetic sheets (excluding the printing equipment already in place). In the 3D printing approach, the cost of the filament for one set of cards was less than $100 in U.S. dollars; the largest cost would be for the 3D printer, which already existed at the university where the cards were produced.

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## Appendix A. List of Consonants and Vowels on the Website

| Symbol | Sample Word | Symbol | Sample Word | Symbol | Sample Word | Symbol | Sample Word |
|---|---|---|---|---|---|---|---|
| p | spot | v | very | i | heat | aɪ | hide |
| $p^h$ | pot | θ | think | ɪ | hit | aʊ | how |
| b | big | ð | the | eɪ | cane | ɔɪ | toy |
| t | stop | s | sit | ɛ | head | | |
| $t^h$ | time | z | zoo | æ | hat | | |
| d | dog | ʃ | ship | ə | about | | |
| k | sky | ʒ | treasure | ɚ | teacher | | |
| $k^h$ | can | h | hello | ɝ | bird | | |
| ɡ | game | ʧ | child | u | do | | |
| m | my | ʤ | jump | ʊ | book | | |
| n | not | w | wet | oʊ | no | | |
| ŋ | sing | ɹ | rock | ɔ | call | | |
| ɾ | city | j | yes | ʌ | up | | |
| f | fast | l | lock | ɑ | hot | | |

*Note.* In most cases, the target consonant sound is the first sound in each word and the target vowel sound is the only vowel in the word. Where this does not apply, the letters corresponding to the target sounds are underlined.

## Appendix B. Pre- and Post-Instruction Interview Questions

The following questions were sent in Spanish to the study's participants. The first set (1–6) was sent prior to the 10-week instructional period. The second set (7–11) was sent following instruction.

**Pre-Instruction**

1. What are the most difficult aspects of English pronunciation for you?
2. How do you usually study or practice English listening and pronunciation?
3. On average, how often do you listen to English during a week (e.g., English media)?
4. Do you listen mostly to American English or other varieties of English (e.g., British)?
5. In what ways do you try to improve your English skills? Examples:
    a. Listening to music with lyrics in English
    b. Listening to various websites (e.g., YouTube, websites designed for English practice)
    c. Listening to television, films, audio materials related to books in English
    d. Paying special attention to specific sounds
    e. Repeating after native speakers of English (e.g., shadowing speakers on recordings, television)
    f. Speaking with other people in English
    g. Asking other people to give you feedback on your pronunciation
6. Do you have a special goal in improving listening and speaking skills in English?

**Post-Instruction**

7. Do you think your listening skills have improved as a result of the instruction?
8. Do you think your speaking skills have improved as a result of the instruction?
9. Are you thinking of changing any listening or speaking strategies as a result of the instruction?
10. Do you have any suggestions for the improvement of the instruction that you received?
11. Do you have any suggestions for the improvement of the materials (tactile cards and website) that you used?

## About the Authors

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