# Teachable Machine: Approachable Web-Based Tool for Exploring Machine Learning Classification

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## Abstract
Teachable Machine (teachablemachine.withgoogle.com) is a web-based GUI tool for creating custom machine learning classification models without specialized technical expertise. (Machine learning, or ML, lets systems learn to analyze data without being explicitly programmed.) We created it to help students, teachers, designers, and others learn about ML by creating and using their own classification models. Its broad uptake suggests it has empowered people to learn, teach, and explore ML concepts: People have created curriculum, tutorials, and other resources using Teachable Machine on topics like AI ethics at institutions including the Stanford d.school, NYU's Interactive Telecommunications Program, the MIT Media Lab, as well as creative experiments. Users in 201 countries have created over 125,000 classification models. Here we outline the project and its key contributions of (1) a flexible, approachable interface for ML classification models without ML or coding expertise, (2) a set of technical and design decisions that can inform future interactive machine learning tools, and (3) an example of how structured learning content surrounding the tool supports people accessing ML concepts.

## Author Keywords
Interactive ML; human-centered ML

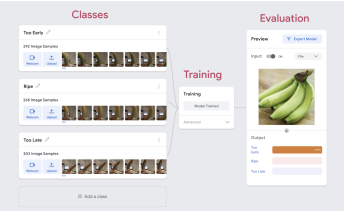


**Figure 1:** Teachable Machine Interface teachablemachine.withgoogle.com/train

## ACM Classification Keywords

H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

## Introduction and Motivation

Machine learning (ML) is increasingly prevalent in daily life, powering recommendation systems, translation, speech transcription and more. Yet, many people whose lives are affected by ML lack detailed understanding of how it works and have no access to creating their own models, one aspect of deepening digital inequality. With numerous instances of algorithmic bias and the widespread potential for the social impact of ML to spread to new arenas of everyday life, it is essential to enable people with diverse expertise and experiences to engage with ML. One approach to broadening engagement with ML is with tools that enable users without technical knowledge to create their own ML models.

Teachable Machine is a web-based interface that allows people to train their own ML classification models, without coding, using their webcam, images, or sound. It uses transfer learning, an ML technique, to find patterns and trends within the images or sound samples, and create a simple and easy classification model within seconds. With transfer learning, a user is able to add their own data and retrain a model on top of a previously trained base model that has learned a specific domain from a large dataset. For example, the base model(mobilenet) for the images portion of Teachable Machine was originally trained to recognize 1000 classes (like dog, phone, bed, trombone, etc). The underlying traits that mobilenet used to recognize those classes can be used to identify new classes the user defines. This complexity is hidden from users, who simply benefit by needing less data and training time to create useful, accurate models.

We designed Teachable Machine to be used by educators to easily teach concepts of ML; for prototypers, designers & researchers to quickly test interactive concepts with ML; and for users with disabilities to create personal models they can control. Since launch, people have trained over 125,000 ML classification models with it.

The primary contributions this project makes:

- A generalized, flexible-input interface for making ML classification models that can be easily learned and used without prior experience or expertise in ML or coding.
- A set of product decisions that enable learning and experimentation for new users of ML.
- An example of how content surrounding the interface allows people to learn ML concepts.

## Related Work

Human-centered machine learning (HCML) enrolls ML to better serve users' goals and accommodate particular contexts [29, 17, 15]. Emerging perspectives in HCML call for enabling people without technical knowledge to develop their own machine learning models [29].

Interactive machine learning (IML) [13] responds to this call, enrolling user input to develop and refine ML models, leveraging users' domain and contextual expertise [9]. For example, Fiebrink's Wekinator helps composers and performers use ML for creative practice [14]. Diaz et al. enroll IML for game developers [12]. Katan et al. use IML to engage people with disabilities in musical interface development [20]. These tools combine machine learning with human domain and contextual expertise.

Many IML tools target novice users without specific technical or domain expertise. For example, Crayon is an

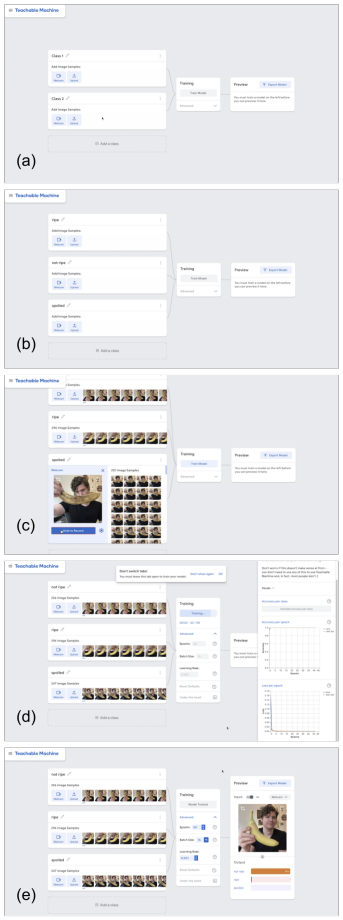


**Figure 2:** Example user flow for training a banana ripeness image classifier. (a) Starting interface. (b) User is able to add classes or rename them. (c) User imports example images to each class. (d) Train classifier, can monitor the performance of the model over time. (e) User tests new inputs, model predicts with a percent which class. User is also able to export model for future.

IML system for image classification [13]. Scratch Nodes ML enables children to create gesture classification models that integrate with Scratch [8]. Webcam Pacman invites players to train their own classifier of webcam images as an Pacman-playing interface [1]. Machine Learning for Kids is an educational tool for guiding children through ML training [22]. A CAPpella is a tool for context-aware programming by demonstration [11]. Françoise and Bevilacqua developed a tool for novice users to generate interactive sounds from gestures [16].

Teachable Machine builds on and extends related work. It provides an approachable yet well-featured interface for children and adults to create their own ML classification models through its website. It enables users to train classifiers for an arbitrary number of classes, provides data collection + classification, model training, and model evaluation in the same interface, and trains on-device (which results in faster performance and enables training to be free.). In the following sections, we outline the design of Teachable Machine, provide preliminary descriptions of its widespread adoption and use in-the-wild, reflect on what that adoption implies, and consider next steps.

## Creating a model

Common steps of making an ML classification model–data collection and classification, training, and evaluation–are laid out left-to-right to indicate the causal relationship and order of steps for new users (Fig. 1). To create a model, the user first selects whether the model should classify images, sounds, or poses as input. Then the user creates the classes they want the model to learn to classify; in Fig. 1, 2, these are 'too early', 'ripe', and 'too late'. For some data types, such as audio, users are shown they need to provide a minimum number of examples. They train the model by clicking clicking "train" in the middle "train" panel. Then they evaluate the quality of their model in the rightmost "evaluation" panel. They can test the model with live data, such as webcam or microphone, or recorded data, such as still images. They can then optionally export their model for use elsewhere, such as p5.js, the Coral Dev Board, or their own applications.

## Going Under the Hood

Here we outline a set of technical decisions in the tool that enable learning and experimentation.

*Data privacy: helping users feel safe experimenting*
Teachable Machine trains users' models within the browser on their device, with their own data, without that data leaving their computer. Furthermore, it is possible to download that trained model locally, using TensorFlow.js. This allows for a greater sense of privacy and ownership than systems that send and process data to a remote machine, and a more flexible and less permanent structure to play and experiment with machine learning, without needing to worry about storing and saving large files, datasets, or models to the cloud.

*Model customization: tweaking training parameters*
For users that want more control over model training, Teachable Machine provides two expandable panels: an "advanced" training section for hyperparameter tweaking and an "under the hood" panel for model evaluation visualizations. The "advanced" panel sits in the training module and can expand to reveal options for tuning the parameters of: epochs, batch size, and learning rate.

The default parameters shown in Figure 3-a are for training image classification models. All new image classification projects default to these parameters - although most users will never need to tweak them for

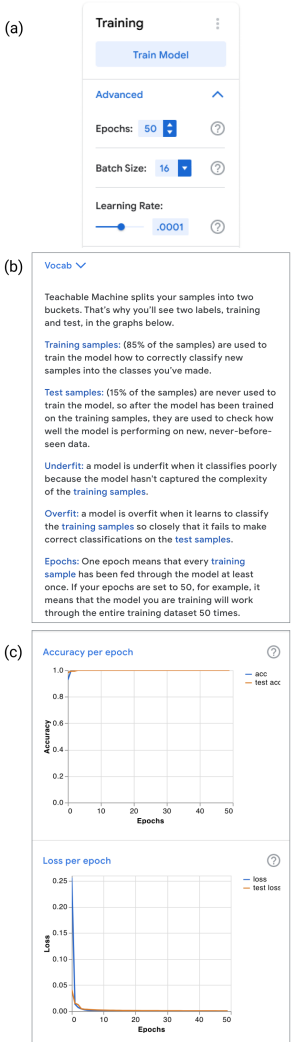


**Figure 3:** Example advanced options on Teachable Machine. (a) Training parameters can be adjusted. (b) Vocabulary to support all users learning (c) Advanced Panel to measure model performance.

satisfactory results. We discovered these parameters through trial and error - making informed guesses based on user research about the average number of samples, average number of classes, and task complexity exhibited by Teachable Machine users.

*Model evaluation: helping users evaluate their models*
After a user has trained a model, a secondary panel is made available to help them evaluate it. Is it accurate? Can it be improved? How quickly has the model learned?

Teachable Machine withholds 15 percent of samples (taken proportionally from each class) to use as a validation dataset, so the accuracy and loss visualizations (Figure 3-c) plot both the training and validation dataset results. While the tool does not explain how to interpret the charts, we provide a set of vocabulary words described in simple language for beginner users (Figure 3-b). Advanced users can deduce whether a model might have underfit, overfit, or learned appropriately.

## Usage Across Different Domains

We've seen individuals publish their use of Teachable Machine in ways that imply the tool enables learning and exploration. These uses are likely not inclusive of every use, because we do not require users to register with us or provide documentation of their usage, but they do provide compelling evidence that the web tool can be easily learned, used, and taught, even by those without prior experience in ML or coding.

**Educators have used it to introduce concepts of AI:**

- Actua, a Canadian STEM education nonprofit, cites it as one of the "tools we find particularly useful for introducing these key concepts [of AI]" [3]
- Blakeley H. Payne has used it in her MIT AI Ethics Education Curriculum [28], to explore supervised learning and explain concepts of bias:
"Students are introduced to the concept of classification. By exploring Google's Teachable Machine tool, students learn about supervised machine learning. Then students are asked to build a cat-dog classifier but are unknowingly given a biased dataset. When the classifier works better on cats than dogs, students have the opportunity to retrain their classifiers with their own new datasets."

These show how Teachable Machine has been useful for educators who want to introduce ML concepts to students, while not watering down concepts like bias and fairness, and even letting students explore how bias comes about in machine learning systems themselves.

Moreover, based on use of the tool amongst teachers & curricula, we posit that TM facilitates active learning of AI concepts by requiring students to interact with those concepts by making models themselves. The authors heard anecdotally from administrators, educators, and students that there is a dearth of tools and activities to support active learning in AI.

**Integrating machine learning in higher education:**

- Yining Shi (NYU ITP Professor) used it to teach her Machine Learning for the Web students the basics of ML classification, and her students used it to make their own projects. [30]
- Michelle Carney (Stanford d.school, author of paper) used Teachable Machine in an assignment to allow grad students from diverse disciplines to explore applying ML to their own domain, such as

botany for plant classification or law text classification. [10]
- Christine Meinders (Cal Arts, California College of Arts) used Teachable Machine in conjunction with p5.js and Coral dev boards for undergraduate student final projects, exploring training students own facial expressions or movements. [23, 24]

These usages and the resulting projects from students suggest that the tool can be useful not just as a way to learn the concepts of ML, but also as a resource for students' creative projects, even if those students have no prior ML experience.

**Usage within accessibility:**

- Research team at Google is using Teachable Machine to create bespoke applications for users with ALS. One user was able to trigger audio playback with a sequence of facial expressions using a model trained with Teachable Machine. [18]

**Users authoring tutorials for Teachable Machine:**

Users have authored their own tutorials in multiple languages that we did not support with the launch of the tool - see tutorials in Japanese [21], Korean [19], Turkish [26], Tamil [7], Hindi [5], Khmer [4], Vietnamese [2].

This suggests to us that the tool is easy enough to learn that practitioners feel comfortable enough with it to explain it to others, even in languages other than English, the language we released the tool in.

**Users have also been using the tool to prototype ideas that require machine learning classification:**

- Babusi Nyoni using Teachable Machine to create blackgirlhair.js [25]
- Base Design used it to prototype a cookie-drawing recognizer. [31]
- Atharva Patil used it to build a posture detector that blurs the web page if you slouch. [27]

These usages suggest to us that users find Teachable Machine an easier tool to prototype with than existing workflows, and also that it enables people with less expertise to prototype using ML classification.

**Enabling personal empowerment and agency:** Users have communicated that they feel more empowered to work with ML as a result of Teachable Machine.

- They have commented on Twitter and YouTube, such as mb09 on Dan Schiffman's YouTube video about Teachable Machine said: "Thanks for the new video! Always appreciate the interesting and inspiring content from here. It certainly helps to eliminate the fear barrier to try new things!" [6]
- Christine Meinders, Professor of AI, Culture and Creativity at Cal Arts and California College of Arts, founder of Feminist.AI [23, 24]: "I use teachable machine in my classes and community workshops via Feminist.AI. It's a great way for students to actually visualize what it means to have diverse data collection, and quickly understand issues with training. The ability to record while moving allows for unique data collection, adding or removing data, and retraining models. It's great because you can instantly understand changes. Additionally, it has the ability to name your class, giving it a sense of personalization. This allows anyone from any

background to come in and play with Machine Learning for themselves. This is huge."

## Discussion

Teachable Machine is empowering people to create their own machine learning classification models, including:

- Educators using it in the classroom and creating their own curriculum and content.
- Enabling interactive ML to be culturally sensitive (e.g. starting a conversation about subjective classification, like banana ripeness, which can differ between people)
- A clearer mental model about what ML is doing, like understanding the relationship between inputs and outputs of the model
- Working immediately out of the box, while allowing users to dive in deeper to customize and explore the models themselves, export and use those models, and work with multiple inputs (cameras, microphones, images) and outputs (arduinos, coral dev boards)

This work is important as ML/AI impact many aspects of our lives. By providing fun and engaging examples that invite people to play with these techniques, we are allowing people to understand how ML works without needing to learn coding. Creating models themselves also allows people to question the inputs and outputs of the models around them in their daily life - for example, if you train a model on bananas and you prefer green bananas, that might be 'not ripe' to other people, therefore your bias in ripeness is creeping into the system. We believe that this approach – making technology teachable – is an important shift for ML/AI.

- **Who can use ML:** Just as Visual Basic opened up database programming to a substantially larger audience, we can do that for ML/AI.
- **How ML is used:** Now ML is a tool in users hands, not something that happens to them. Enable users to teach their technology in new ways through models that they – not a central source – create and control.
- **Why ML is used:** Now I can use ML to solve the problems that matter to me and my community.

This shift could have a cumulative, positive effect for society. Using ML hands-on could be one of the most effective ways to gain an intuitive understanding of how it works. And as ML is increasingly baked into society, understanding how these systems work is critical – so we can all ask the right questions.

## Future Work

Our future work includes internationalization, user studies, and expansion to include new model types & input types such as hand models & text classification.

## Conclusion

Teachable Machine is not only an education tool, but a way for anyone to quickly and easily create a ML classifier using only their web browser in a matter of minutes. Already, we have seen its adoption in classrooms, curriculum, and with nontraditional ML enthusiasts creating their own projects as well, and we continue to see new examples of how it has enabled others to learn about ML & create their own models.

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