

# Modeling Collaborator: Enabling Subjective Vision Classification With Minimal Human Effort via LLM Tool-Use

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## Abstract

From content moderation to wildlife conservation, the number of applications that require models to recognize nuanced or subjective visual concepts is growing. Traditionally, developing classifiers for such concepts requires substantial manual effort measured in hours, days, or even months to identify and annotate data needed for training. Even with recently proposed Agile Modeling techniques, which enable rapid bootstrapping of image classifiers, users are still required to spend 30 minutes or more of monotonous, repetitive data labeling just to train a single classifier. Drawing on Fiske’s Cognitive Miser theory, we propose a new framework that alleviates manual effort by replacing human labeling with natural language interactions, reducing the total effort required to define a concept by an order of magnitude: from labeling 2,000 images to only 100 plus some natural language interactions. Our framework leverages recent advances in foundation models, both large language models and vision-language models, to carve out the concept space through conversation and by automatically labeling training data points. Most importantly, our framework eliminates the need for crowd-sourced annotations. Moreover, our framework ultimately produces lightweight classification models that are deployable in cost-sensitive scenarios. Across 15 subjective concepts and across 2 public image classification datasets, our trained models outperform traditional Agile Modeling as well as state-of-the-art zero-shot classification models like ALIGN, CLIP, CuPL, and large visual question answering models like PaLI-X.

## 1. Introduction

The field of computer vision has primarily focused on recognizing concepts that are objectively agreed upon, such

\*This work was done during an internship at Google.

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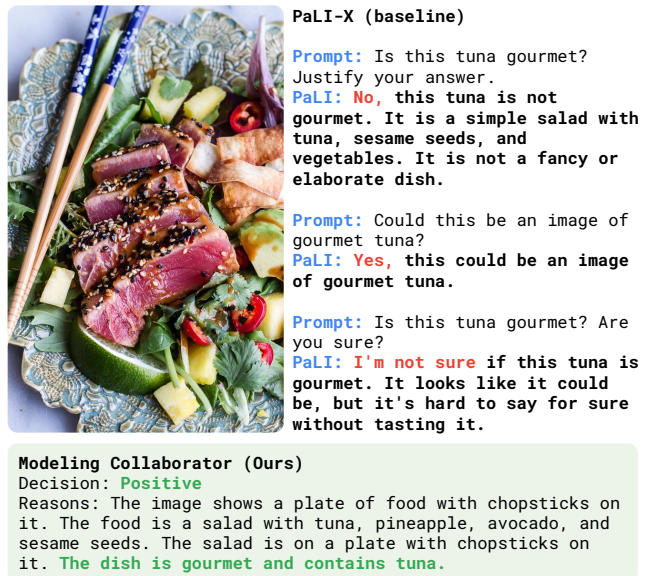


Figure 1. We introduce Modeling Collaborator: a framework that allows anyone to train vision models using natural language interactions and minimal effort. We show that today’s best models (e.g. PaLI-X [6]) change their answers depending on the prompt when classifying subjective concepts like gourmet tuna. Meanwhile, Modeling Collaborator uses LLMs and tool-use to train vision models by interacting with users to carve out the concept space.

as dogs, cats, or cars [11, 28, 30]. Even research on fine-grained recognition (e.g. “black footed albatross”) and compositional concepts (e.g., “red car next to a motorcycle”) have universal consensus [22, 27, 32, 35]. However, many practical real-world vision applications frequently involve recognizing subjective concepts that suffer from significant disagreements amongst individuals. Applications include predicting emotions, measuring aesthetic appeal, or content moderation [10, 25, 26, 45]. A content moderator

needs a model to identify unsafe content according to their definition of what constitutes as *unsafe*; a food critic might not consider a tuna sandwich to be gourmet while others might (Figure 1). To operationalize these applications, we need user-centric training frameworks that enable anyone to train subjective vision models.

Recently, Agile Modeling formalized the process for turning any visual concept into a vision model through a user-in-the-loop framework [51]. Their work concluded that crowd workers struggled to produce labels that were consistent with the user’s concept definition. Instead, they proposed an active learning algorithm, where the user iteratively labels a series of training images themselves. Unfortunately, this process is tedious, repetitive, and labor intensive; users had to label  $\sim 2000$  images, which on average took 30 minutes to train a binary classifier.

Existing processes fall short because they do not leverage a key capability that humans possess. People are adept at breaking down complex subjective concepts into more manageable and objective components by applying first-order logic [14, 36]. This ability can be explained using Susan Fiske’s Cognitive Miser Theory: people decompose complex work to avoid high cognitive load [13]. People apply the same process to define complex concepts such as “unsafe” and “gourmet”. For instance, one food critic might decompose the subjective concept of “gourmet” as images that need to at least contain “tuna”; if it is “ahi tuna”, then it is likely gourmet; if it is “canned”, then it is unlikely to be gourmet; if the dish is a “sandwich”, then it is still not gourmet. This decomposition of the subject concept “gourmet” into conjunction clauses of objective concepts “ahi tuna”, “canned”, and “sandwich” is a simple *non-laborious*, cognitively effortless conversion.

With this grounding, we deliver **Modeling Collaborator** which empowers users to build classifiers while minimizing manual effort. Instead of asking users to annotate thousands of images [51], Modeling Collaborator requires 100, along with a few natural language interactions that help decompose subjective concepts into its constituent sub-components. To enable Modeling Collaborator, we leverage advancements in large language models (LLMs) [2, 3, 9, 12, 37] and in particular, their ability to use vision-language models (VLMs) [6–8] and other tools [19]. When users have a concept in mind and use Modeling Collaborator, it employs an LLM, which breaks the concept into questions that are digestible for a Visual Question Answering (VQA) model [8]. The LLM then summarizes the answers provided by the VQA model and performs reasoning through chain-of-thought [57] to classify new images as positive or negative examples of the concept. Users are only asked to manually label a small 100 image validation set. Finally, Modeling Collaborator labels a large amount of unlabeled images available online and uses it as distillation

data to train a light-weight deployment-ready vision model.

Our method is shown to outperform existing zero-shot methods (CLIP [43], CuPL [41] and PaLI-X [6]), especially on harder subjective concepts. When compared to the original Agile Modeling [51] our system exceeds the quality of crowd-raters on hard concepts while simultaneously reducing the need for manual user-provided ground-truth by orders of magnitude. By reducing the barriers of manual effort and resulting costs needed to develop classification models, it will empower users to rapidly convert their ideas into reality. This, in turn, has the potential to usher in a new wave of end-user applications.

## 2. Related work

Our work draws on advances in VLMs and LLMs and provides an improved solution to the recently introduced Agile Modeling problem.

**Agile Modeling.** Inspired by agile software development, Agile Modeling [51] focuses on rapid development of image classification models. In addition to speed, Agile Modeling aims to tackle the challenges posed by subjective vision models. As classification tasks become more nuanced, user interaction becomes increasingly crucial. However, it is important to note that the human-in-the-loop approach can be expensive due to the need of continuous human involvement and expertise. While this work aims at reducing time users spend on tuning their classification models, we propose an assisted method to automate parts of the pipeline and eliminate crowd-rater involvement.

**Vision-language models (VLMs).** In the rapidly evolving domain of VLMs, two primary streams have emerged: contrastive and generative models. Contrastive models, such as CLIP [43] and ALIGN [23], leverage large-scale datasets to directly learn visual concepts from raw text, enabling high-accuracy zero-shot classification on open vocabularies [11, 17]. Generative models such as PaLI [6–8, 56] and GPT-V [37, 38] focus on generating text from a combination of visual and text inputs. For instance, PaLI, trained on a vast collection of image-text pairs in various languages, achieves top performance across a range of vision and language tasks. Similarly, GPT-V allows the processing of image inputs, thereby enhancing the applicability of language models to multimodal tasks. Other methods such as CoCa [54, 63] proposed a hybrid approach for simultaneously learning with generative and contrastive objectives. Despite their strength, VLMs capture visual data semantics, often prioritizing salient image features over nuanced visual cues. For instance, CLIP embeddings are intentionally compressed to encapsulate its most prominent subject [49]. Additionally, PaLI may struggle to provide detailed descriptions of complex scenes with numerous objects, as its training data predominantly lacks detailed annotations. In contrast, our proposed method is more stable and less sensitive

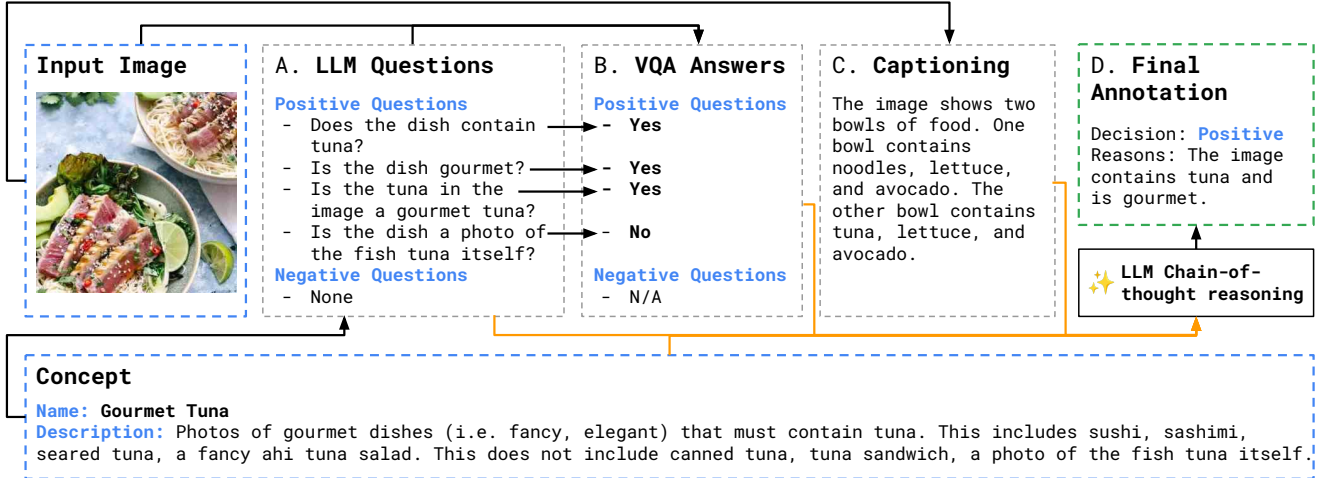


Figure 2. Modeling Collaborator Annotator system. For a given image, concept name, and description, the Annotator outputs a positive or negative label. Based on the name and description of the concept, the LLM generates relevant atomic questions to ask a VQA model (PaLI VQA in our case) (step A). These questions are fed into the VQA model that typically outputs a yes/no short answer (Step B). Additionally, we use a captioning version of PaLI (Step C) to generate a detailed description capturing as much detail as possible from the image. Finally, the LLM goes through a chain-of-thought reasoning process to output a decision and rationale (Step D).

to question phrasing as observed in Fig. 1.

**Large language models (LLMs) and tool-use.** Large Language Models (LLMs) have revolutionized the landscape of artificial intelligence [1, 3, 12, 40, 55], particularly in the field of natural language processing (NLP) and cognitive reasoning. By leveraging advanced methodologies such as chain-of-thought reasoning [57], few-shot learning [4, 39], and tool-use [21, 46], these models demonstrate exceptional performance across a wide spectrum of downstream tasks [44]. They can operate across various modalities and a broad range of applications while maintaining high performance without the need for additional training. Recent progress in integrating external tools with LLMs [5, 20, 21, 29, 62] has yielded systems like Toolformer [46]. This approach makes intelligent decisions about which APIs to invoke, optimizing the timing, arguments passed, and the subsequent assimilation of the results into future token predictions. This enhances zero-shot performance across a variety of tasks, establishing a solid foundation for LLMs to operate beyond their inherent capabilities. For fine-grained VQA, AVIS [20] introduces an autonomous information-seeking mechanism. By dynamically leveraging an LLM in tandem with external tools, it adeptly traverses a combinatorial search space. This is achieved through its unique approach of mimicking human decision-making processes, crafting a transition graph that guides the LLM’s strategic decisions. Another tool-use enabled LLM system is ViperGPT [52], which embodies an innovative approach to tackling visual queries. It leverages a code-generation strategy that enables the seamless integration of vision-and-language models through the generation of Python code. This method,

along with other similar methods (MMReact [61], HuggingGPT [50], Chameleon [34], and Visual ChatGPT [58]) circumvents the need for extended training and ensures resilience across a diverse set of visual tasks. Collectively, these systems highlight the burgeoning synergy between LLMs and external tool use, pushing the frontiers of what LLMs can achieve. In our work, we adopt and extend ideas from these approaches to tackle the problem of subjective image classification.

**Customized prompts via language models.** Customized Prompts via Language models (CuPL) [41] leverages CLIP’s capabilities [43] to achieve zero-shot image classification. CuPL measures the similarity between an image and each visual class to perform classification. Typically, the classes are passed into CLIP’s text encoder within a template such as “photo of a bird” for the class bird. CuPL employs GPT [3] to generate more comprehensive text descriptions for each class before feeding into CLIP. This straightforward and zero-shot approach yields improved accuracy across various zero-shot image classification benchmarks. However, its evaluation has been limited to objective classification tasks and not on nuanced or subjective visual classification tasks. This approach for automatically annotating data improves upon CLIP but suffers from the same limitations compared to our work.

### 3. Method

We propose an end-to-end system that streamlines the development of classifiers for nuanced visual concepts, addressing the limitations of traditional classifier development

methods. The system consists of three core components, described in detail in the following subsections: (a) data mining, (b) annotation, (c) model training with active learning.

To build a classifier for a new concept, the user first provides a concept name and an optional description. The system then automatically mines images relevant to the concept and annotates them using a mixture of Large Language Models (LLM), Vision-Language Models (VLM), and Visual-Question-Answering (VQA) models. The annotated images are used to train a basis classification model, which is further refined through multiple rounds of active learning, resulting in a highly accurate classifier.

This setup mirrors the workflow of traditional classifier development, but it eliminates the need for costly and time-consuming human annotation which is a significant bottleneck in traditional methods. The Modeling Collaborator Annotator component, powered by LLMs and VLMs, enables zero-shot image labeling and drastically minimizes our dependence on user annotations.

### 3.1. Data mining

Mining quality data for training has traditionally been a labor-intensive process. This process begins with the clear definition of a concept, followed by the hunt for relevant images, and ends in the manual annotation of each of these images [11, 30]. Particularly for nuanced visual tasks, there is a possibility that certain subtle visual patterns might be overlooked during data collection. Consequently, to ensure a comprehensive capture of all visual patterns, multiple iterations of refinement may be needed. In traditional Agile Modeling [51] this challenge is addressed by soliciting *users* to annotate data or generate new search queries to find more image examples. Each query results in a new semantic image search algorithm [23, 43] to gather other similar positive image examples for annotation from the public domain (LAION Dataset) [47]. Even with user intervention, *user* queries may overlook essential cues, potentially leading to a deficit of hard negatives or a lack of coverage in specific visual modes. Additionally, the labels can vary between users, leading to potential human biases.

To address human bias and minimize manual effort, we propose a data mining algorithm based on LLM chain-of-thought reasoning. While LLMs are not inherently unbiased [15] and may reflect biases present in their training data, they can assess a wider range of concepts at large scales from their extensive knowledge base, thus identifying a broader array of potential examples more efficiently. First, we prompt the LLM to generate multiple positive and negative queries based on a concept’s name and its description. Note that we do not directly assign images as positive or negative based on the query; rather, the goal is obtain representative images spanning both positive and hard-negative examples. To increase coverage and diversity, we expand

the queries by instructing the LLM to apply various *mutations*. For example, we may ask the LLM to iteratively come up with broader or narrower versions of the queries, or come up with variations for specific parts of the queries. Drawing parallels to Agile Modeling, we use each query to extract image samples from the public domain [47].

### 3.2. Modeling Collaborator Annotator

Fig. 2 describes the image annotation process. Our system effectively orchestrates the annotation process leveraging LLM’s ability to invoke VLMs and other tools. It comprises three primary AI-driven modules: an LLM, a Captioning VLM [56], and a VQA VLM [6]. The automated annotation process is structured as follows:

**Concept initialization:** Initially, our system receives a concept name (e.g., `gourmet tuna`), and optionally a concept description. If a concept description is absent, the LLM generates an initial description. This template can be modified by the user to cover all specifications and carve-outs.

**Attribute Extraction:** Based on the concept specifications, the LLM identifies objective attributes associated with the concept, such as “image contains tuna”, “is tuna sandwich”, and “is tuna steak”.

**Attribute decomposition:** The LLM decomposes complex attributes into more granular and atomic attributes.

**Question generation:** The LLM then formulates a series of questions tailored for the VQA model. Examples include “does the image contain food”, “is the food tuna”, and “is it tuna steak”.

**Visual assessment:** When an image is input, the VQA model processes these questions, yielding concise answers for each. Concurrently, the Captioning VLM provides a comprehensive description of the image.

**Final annotation:** With the textual data from the VLMs and the user’s initial concept specification, the LLM employs chain-of-thought reasoning. It annotates the image as either positive or negative, also offering insights into its decision-making process.

Our approach utilizes the strengths of VLM, VQA, and LLM models while simultaneously avoiding their shortcomings. For example, VLMs, despite their capabilities, often struggle with nuanced and subjective concepts in classification tasks. Their performance hinges on the breadth and quality of training data, potentially leading to biases or gaps in understanding [53]. Ambiguities in language and the inherent subjectivity of certain questions can further challenge their accuracy [33]. Moreover, these models, lacking real-world context and experiential understanding, might miss deeper cultural or emotional nuances [16]. Thus, while powerful, VLMs have inherent limitations in addressing intricate or subjective visual-linguistic tasks. Fig. 1 shows an example VLMs’ (PaLI-X [6]) sensitivity to prompts.

VLMs are primarily designed for understanding and an-

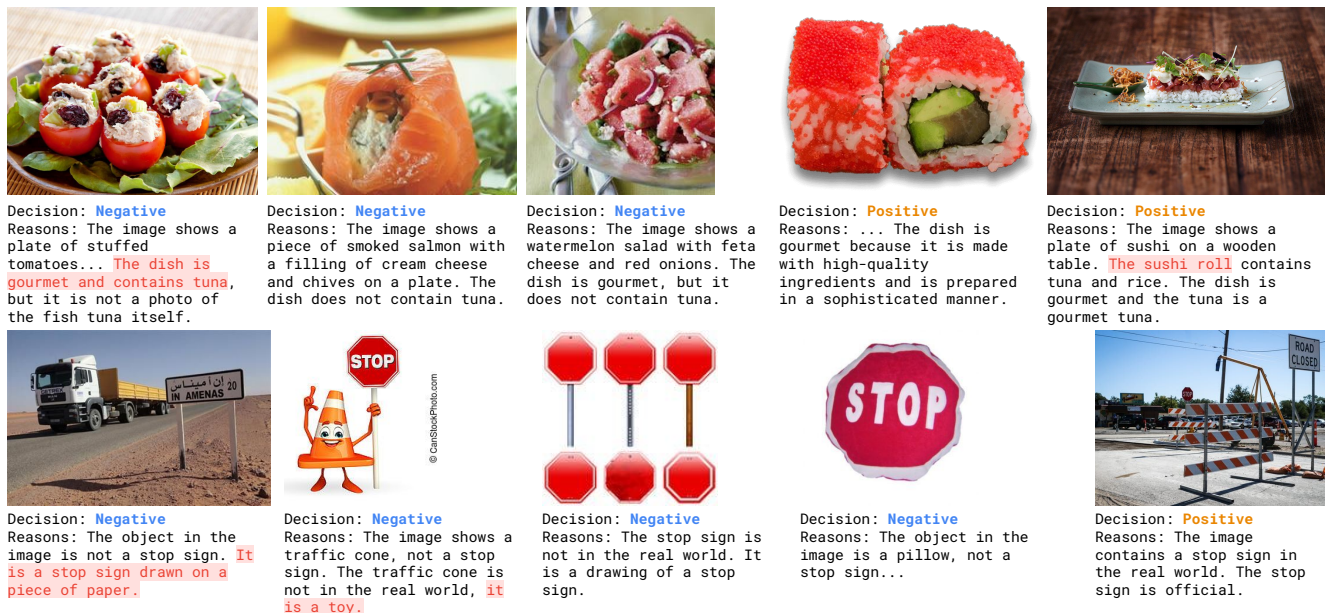


Figure 3. Modeling Collaborator Annotator examples for the concepts `gourmet tuna` (first row) and `stop sign` (second row). Hard negatives mined from the LAION dataset are shown in addition to some actual positives for the visual concept. The Modeling Collaborator Annotator is able to label the images as positive or negative as well as provide rationale. In some instances, the rationale could be incorrect (highlighted in red) due to error in VQA responses or hallucinations from the LLMs. Some of the reasons have been truncated for brevity.

swering questions related to visual content, rather than performing deep chain-of-thought reasoning typical of advanced LLMs [33,42,53,59]. While VLMs can comprehend simpler questions about images, they usually operate in a single-shot manner, providing answers based on the immediate visual and textual inputs without extended reasoning. On the other hand, LLM question answering quality can be significantly improved through chain-of-thought reasoning, maintaining a coherent line of thought across extended text. Other techniques such as prompt chaining involve using a model’s output as part of the subsequent input, simulating a sustained dialogue or iterative reasoning. Additionally, to extract deeper insights, users can guide LLMs with specific instructions, such as asking the model to think step-by-step [60] or weigh pros and cons, thus simulating a more deliberate reasoning process [3].

### 3.3. Training and active learning

While one could directly use the annotator as a model, this is prohibitive in many scenarios because of the high inference cost. For this reason, we adopt an approach similar to [51] for model training and active learning. Specifically, we first extract image features from a foundation vision model (CLIP or ALIGN) [23, 24]. We then train a shallow multi-layer perceptron (MLP) with layer sizes (128, 128, 128) to perform binary classification for the given concept. This can also be viewed as student-teacher distillation [18] where we use the LLM-based annotator as

the teacher model. We use a learning rate of  $3 \times 10^{-4}$ , a batch size of 512, and optimize using AdamW [31].

After the initial model is trained, we perform multiple rounds of active learning. Each active-learning iteration consists of three stages. First, the lightweight classification model is applied to a large database of unlabeled images (LAION [47]). Then, we perform stratified sampling to acquire candidate images for further AL rounds [51]. The intention is to capture hard negatives and hard positives that will boost precision and recall respectively. Second, our LLM-based annotator is autonomously applied to the selected images, providing additional training ground-truth. Thirdly, the student classifier is retrained, leveraging all the extant labeled data. We experiment with both margin sampling and stratified sampling techniques [48] to mine examples during this active learning phase. The overall system thus adeptly balances between exploration (achieved via data mining through text search queries and expansion) and exploitation (achieved via active learning to mine visual modes that reduce model uncertainties).

### 3.4. Implementation details

As a large language model, we use PaLM 2 [2, 9] which was trained on a variety of different tasks, all of which helps PaLM 2 learn different aspects of language. Additionally, we use both the VQA and MMIT (multimodal instruction-tuned [56]) variants of PaLI-X [6]. The particular choice of foundation models is based on their SOTA performance

at the time of writing. These models have not been further trained or fine-tuned in this work.

## 4. Experiments

We present our experimental setup and results with three takeaways. First, we show that Modeling Collaborator Annotator outperforms other zero-shot methods (CLIP [43], CuPL [41] and PaLI-X [6]). Second, while Modeling Collaborator Annotator is able to beat state-of-the-art methods in both easy and hard concepts, we see much larger gains on harder and more subjective concepts. Finally, when using our end to end system, we can produce deployable models of competitive quality with minimal *user* annotations (100 annotations vs. 2,000 in traditional Agile Modeling).

**Datasets.** In addition to the LAION dataset used for data mining in our system, we evaluate our methods on the public Hateful Memes dataset [26]. For evaluation and user-study, we use the Agile Modeling dataset [51] that is comprised of 14 concepts, each with positive and negative images mined from the LAION dataset. This dataset is split into *easy* and *hard* concepts depending on the zero-shot performance on each concept using CLIP as described in [51].

**Models.** We benchmark Modeling Collaborator Annotator against state-of-the-art zero-shot and open-vocabulary classifiers: CLIP [43], CuPL [41], and PaLI-X (55B) [6] as a generative VQA model. We evaluate CLIP by embedding the name of the concept and measuring the cosine similarity to each image embedding. CuPL uses the same technique but instead of embedding the concept name directly, we embed a description of the concept generated by an LLM. Both GPT3 and PaLM 2 models were experimented with but we chose PaLM 2 since it produced superior results. In the case of CLIP and CuPL, we select an operating point using a grid search maximizing the F1 score on a subset of the training set. We use PaLI-X VQA variant as a classifier by prompting it “*Is this an image of X?*” and we assign a positive or negative prediction based on its answer.

**Annotator Adaptation.** While testing the system, we observed some amount of concept-dependent variability in the Annotator. For example, for simple concepts like “cat” a VLM might already have state-of-the-art performance and our system can even degrade quality in these cases. To address this we implemented six different Annotator *strategies*. While developing a classifier for a particular concept, we have the concept owner build an on-the-fly validation set of 100 images which is then used to select the best performing strategy for that particular concept. Different parameters describing these configurations are explained in the Appendix.

**Users, Crowd, and Modeling Collaborator.** We measure the agreement/alignment with the *user* for both the crowd and automatic annotation methods. The *user* is the source of ground-truth and the person manually annotating the test

set. *Crowd* annotators are given a description and examples by the *user* and asked to annotate images at a larger scale. *Modeling Collaborator* Annotator is able to scale up the annotation process further due to its autonomy and can encapsulate an image set of higher diversity in visual modes. We measure the annotator alignment by comparing the performance (auPR) on the distilled model trained on data annotated by different human and machine annotators.

### 4.1. Modeling Collaborator Annotator

**Modeling Collaborator Annotator outperforms other zero-shot methods.** We show the results of these experiments in Tab. 1. We measure the alignment with the *user* on the held-out test set of the Agile Modeling dataset using agreement scores (precision, recall, and F1). CLIP and CuPL contrastive models suffer from very low precision in favor of high recall. PaLI-X outperforms contrastive models, making it more suitable as a baseline for our proposed Annotator. **We achieve significant gains for subjective (hard) concepts while maintaining equivalent performance for less subjective (easy) concepts.** Tab. 1 shows a significant skew in concept improvement: over 25% of the concepts showed an F1 score gain of 4% or higher, including hateful memes [26] at 15%, healthy-dish at 6%, and stop-sign at 5%, exhibiting substantial improvements in areas requiring more subjective classifications. This trend indicates that our model is particularly effective for complex or subjective concepts, but may offer only marginal benefits for concepts that PaLI-X is already good at. Regardless, a Wilcoxon Signed-Rank Test on the F1 scores comparing our system against PaLI-X yields a statistically significant improvement across all concepts ( $p < 0.01$ ). In addition to classification, our system outputs rationales shown in Fig. 3.

### 4.2. Human-machine alignment

**Modeling Collaborator can produce deployable models of competitive quality with minimal user annotations.** We measure the effect of using varying levels of human and automated annotation in Tab. 2. We note that, while our model cannot exceed the distilled user model performance (distilled on 100% accurate annotations), we can outperform crowd-raters. Our Annotator system significantly outperforms crowd-raters on harder more nuanced concepts (different of 6%). Whereas it slightly under-performs on easy concepts. This is likely due to prediction errors from automated VQA models (PaLI-X) where humans show better performance. In comparison to using other state-of-the-art open-vocabulary zero-shot annotators (CLIP, CuPL and PaLI-X), our system outperforms these methods on both easy and hard concepts. Our fully automated system successfully generates distilled models that match the quality of ones crafted with classical Agile Modeling, with per-

Concept	PaLI-X [6]			CLIP [43]			CuPL [41]			Ours		
	Pre	Rec	F1	Pre	Rec	F1	Pre	Rec	F1	Pre	Rec	F1
<b>Easy concepts</b>												
arts-and-crafts	0.71	0.97	0.82	0.68	0.86	0.76	0.68	0.90	0.77	0.96	0.75	0.84
dance	0.57	0.87	0.69	0.51	0.95	0.66	0.52	0.89	0.66	0.67	0.95	0.79
emergency-service	0.67	0.88	0.76	0.53	0.87	0.65	0.54	0.91	0.67	0.88	0.73	0.76
hair-coloring	0.76	0.97	0.85	0.70	0.99	0.82	0.70	0.99	0.82	0.76	0.97	0.85
in-ear-headphones	0.70	0.96	0.81	0.43	0.95	0.59	0.44	0.96	0.60	0.82	0.86	0.82
pie-chart	0.80	0.96	0.88	0.52	0.80	0.63	0.50	0.92	0.65	0.80	0.96	0.88
single-sneaker	0.65	0.92	0.76	0.51	0.99	0.67	0.51	1.00	0.67	0.70	0.88	0.78
<b>Easy concepts average</b>	<u>0.69</u>	<u>0.93</u>	<u>0.80</u>	0.55	0.92	0.68	0.56	<b>0.94</b>	0.69	<b>0.80</b>	0.87	<b>0.82</b>
$\Delta$										+11%	-6%	+2%
<b>Hard concepts</b>												
astronaut	0.61	0.87	0.71	0.40	0.95	0.56	0.42	0.95	0.58	0.72	0.79	0.72
block-tower	0.45	0.97	0.62	0.38	0.99	0.55	0.37	0.98	0.54	0.89	0.68	0.66
gourmet-tuna	0.52	0.95	0.67	0.29	1.00	0.45	0.29	1.00	0.45	0.52	0.95	0.67
hand-pointing	0.56	0.99	0.71	0.39	0.87	0.54	0.39	0.94	0.55	0.89	0.79	0.74
healthy-dish	0.38	1.00	0.55	0.37	0.99	0.54	0.38	1.00	0.55	0.84	0.61	0.61
home-fragrance	0.57	0.51	0.54	0.40	0.95	0.56	0.40	0.96	0.57	0.57	0.51	0.54
stop-sign	0.61	0.99	0.76	0.48	1.00	0.65	0.49	0.99	0.65	0.83	0.83	0.81
<b>Hard concepts average</b>	<u>0.53</u>	<u>0.90</u>	<u>0.65</u>	0.39	0.96	0.55	0.39	<b>0.97</b>	0.56	<b>0.75</b>	0.74	<b>0.68</b>
$\Delta$										+22%	-16%	+3%
<b>Overall average</b>	<u>0.61</u>	<u>0.92</u>	<u>0.72</u>	0.47	0.94	0.62	0.47	<b>0.96</b>	0.62	<b>0.78</b>	0.79	<b>0.74</b>
$\Delta$										+17%	-13%	+2%
<b>Hateful memes [26]</b>	<u>0.66</u>	<u>0.42</u>	<u>0.51</u>	0.49	<b>0.98</b>	0.66	0.50	0.87	0.64	0.58	0.77	<b>0.66</b>
$\Delta$										-8%	+35%	+15%

Table 1. Teacher performance (Precision, Recall, and F1 scores). Modeling Collaborator outperforms state-of-the-art zero-shot methods including CLIP, CuPL, and visual query answering models (PaLI-X). Underlined results represent the baseline (PaLI-X) with which our performance is compared to (deltas). We bold the best precision, recall, and F1 for easy concepts, hard concepts and Hateful memes dataset.

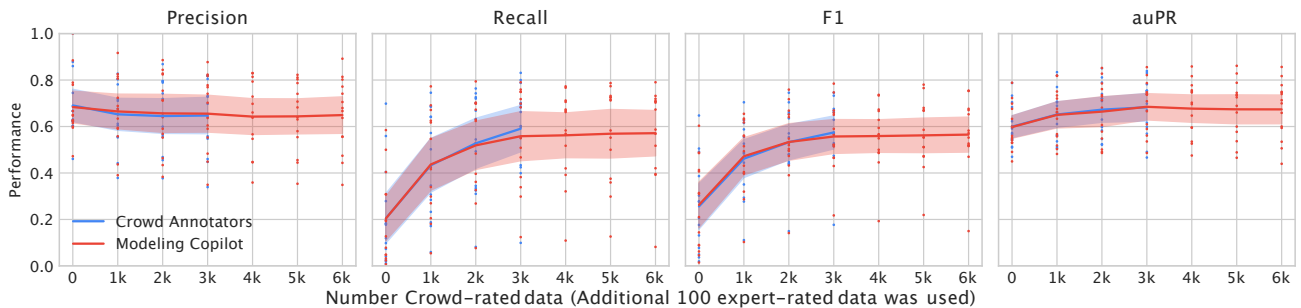


Figure 4. Comparing the contribution of increasingly more training examples annotated by crowd-annotators vs. Modeling Collaborator Annotator (fully automated). The y-axis shows the performance of the final distilled model. When *user* feedback is minimal (100 annotated examples), more crowd-annotators examples improve the final distilled model despite the noisy prediction. Modeling Collaborator Annotator provides similar improvement of performance without any human interactions and can be scaled better to annotate a lot more examples due to its autonomy.

formance within a 2% margin of the *user*'s output. Fig. 4 shows that both crowd-annotators and Modeling Collaborator Annotator can improve the performance of the distilled model, even when *user* feedback is minimal. However, Modeling Collaborator Annotator has the advantage

of being fully automated and can scale to a larger number of examples.

**Modeling Collaborator and other zero-shot and classical methods fail in complex visual tasks that require complex understanding and reasoning.** The effectiveness of

Concept	Human Annotators			Machine Annotators		
	User	Crowd	Crowd	CuPL	PaLI-X	Ours
Dataset size (per concept)	~600	~600	~3000	~3000	~3000	~3000
<b>Easy concepts</b>						
arts-and-crafts	0.77	0.73	0.86	0.78	0.77	0.78
dance	0.69	0.70	0.81	0.72	0.68	0.68
emergency-service	0.75	0.71	0.78	0.59	0.66	0.72
hair-coloring	0.85	0.85	0.83	0.77	0.58	0.80
in-ear-headphones	0.73	0.66	0.67	0.65	0.73	0.72
pie-chart	0.77	0.76	0.76	0.72	0.82	0.82
single-sneaker	0.74	0.64	0.68	0.51	0.61	0.56
<b>Easy concepts average</b>	0.76	<u>0.72</u>	0.77	0.68	0.69	<b>0.73 (+1%)</b>
<b>Hard concepts</b>						
astronaut	0.67	0.71	0.66	0.60	0.65	0.65
block-tower	0.59	0.58	0.45	0.48	0.49	0.50
gourmet-tuna	0.50	0.51	0.35	0.54	0.52	0.52
hand-pointing	0.50	0.56	0.58	0.56	0.81	0.81
healthy-dish	0.59	0.49	0.47	0.42	0.45	0.53
home-fragrance	0.62	0.60	0.69	0.56	0.53	0.53
stop-sign	0.70	0.57	0.55	0.62	0.51	0.64
<b>Hard concepts average</b>	0.60	<u>0.57</u>	0.54	0.54	0.57	<b>0.60 (+3%)</b>
<b>Overall average</b>	0.68	<u>0.65</u>	0.65	0.61	0.63	<b>0.66 (+1%)</b>

Table 2. Quality comparison of different annotators (or teacher models) using the final distilled model performance (auPR). Concept owners provide the highest quality annotations because of their deep understanding of the nuanced concept. Modeling Collaborator annotator provides better quality labels compared with labor-intensive annotations from crowd raters, and compared to other automated methods.

Method	Labeler	# Ex.	F1	Acc	Pre	Rec
Ours (Teacher)	-	-	0.66	0.61	0.58	0.77
CLIP [43]	-	-	<b>0.57</b>	0.53	0.51	0.65
CuPL [41]	-	-	0.51	<b>0.64</b>	0.50	<b>0.87</b>
PaLI-X [6]	-	-	0.51	0.61	<b>0.66</b>	0.42
Ours (Student)	MC	7K	0.56	0.52	0.50	0.64
CLIP+MLP	Human	8.5K	0.48	0.60	0.65	0.38

Table 3. Performance of our method (both Annotator and distilled models) on the Hateful Memes [26] public dataset. Zero-shot and VQA methods are used for comparison.

our method on identifying hateful memes [26], as demonstrated in Tab. 3, is further highlighted by its ability to match fully-trained models without relying on labeled data. Both the teacher and student models outperform the traditional training approach without using any of the training datasets. However, the performance is still low, demonstrating the limitations of our approach.

## 5. Limitations

As our system is an orchestration of LLMs and VLMs, it can suffer from some of the limitations of its atomic components (PaLM 2, PaLI-X, and CLIP). For example, we observed that providing verbose and overly-complex descrip-

tions of simple concepts (cats, dogs, etc.) can actually degrade performance in comparison to simply using PaLI-X. Another issue is that for certain concepts, the CLIP features can lead to poor distilled model quality. One example is `stop sign` (where the stop sign is expected to be a real stop sign in traffic), where the CLIP feature could capture the overall semantics of stop signs, but could not easily discriminate between physical instances vs depictions.

## 6. Conclusion

In this paper, we presented Modeling Collaborator, a novel framework that alleviates the manual effort required to develop classifiers for subjective and nuanced visual concepts. Our framework leverages advancements in large language models (LLMs) and vision-language models (VLMs) to carve out the concept space through conversation and by automatically labeling training data points. We demonstrate the effectiveness of our framework through a set of experiments, showing that it can quickly build visual classifiers for nuanced concepts and outperform both traditional Agile Modeling and state-of-the-art zero-shot classification models. Our work has the potential to significantly reduce the time and effort required to develop classifiers for a wide range of applications including content moderation and aes-



thetic classification.

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## Appendix

### A. Concept names and descriptions

#### A.1. Agile Modeling dataset concepts

**Arts and crafts:** Image must contain arts and crafts.

**Astronaut:** Any picture that shows an astronaut, even if it’s a drawing, clip art, etc. The astronaut should show clearly that they are associated with being an astronaut – usually indicated by a space suit or NASA jumpsuit.

**Block tower:** Image must contain a toy block tower made of legos or wood.

**Dance:** Photos of people dancing.

**Emergency service:** Image must contain emergency service, paramedics, firefighters, police, or rescue teams.

**Gourmet tuna:** Photos of gourmet dishes (i.e. fancy, elegant) that must contain tuna. This includes sushi, sashimi, seared tuna, a fancy ahi tuna salad. This does not include canned tuna, tuna sandwich, a photo of the fish tuna itself.

**Hand pointing:** A picture showing a hand pointing, with just the index finger extended. Does not include pictures of thumbs-up or pictures of hands with more than just the index finger extended. Picture with a straight finger pointing at or tapping a screen are included.

**Hair coloring:** Pictures that focus on people during the process of hair coloring or right after, before & after photos. Negatives: store front of hairdresser, boxes of dye.

**Healthy dish:** Photos of dishes with healthy food that is low in carbs

**Home fragrance:** Photos of any types of fragrances used for houses, including home perfumes, air fresheners for the house, scented candles, essential oils.

**In ear headphones:** Any headphones that are worn inside the ear, rather than covering it up. These types of headphones are inserted into the ear canal. As long as an in-ear headphone is in the picture, it is valid.

**Pie chart:** Any image with a pie chart, which is a circular statistical graphic, which is divided into slices to illustrate numerical proportion.

**Single sneaker on white background:** Images depicting a single sneaker on a white or neutral-colored background (e.g beige). It can be a partial view of a sneaker (e.g. just the sole, or half of the sneaker is in view) but it cannot be just parts (e.g. just the shoe lace) . Negatives include images that have more than one shoe, that have different colored background, or a different style of shoe.

**Stop sign:** This includes photos of real-world, official stop signs. Imagine we would want to detect such stop signs for self-driving cars. Positives include any stop sign photos, including those temporary ones included in construction, or held in hand by a construction worker. If there’s a stop sign on a banner or ads poster, even if it’s in traffic, it would be a negative (we don’t want the self-driving car to stop at that). Clip art or indoors stop sign are negative

#### A.2. Public dataset concepts

**Hateful memes:** Memes that are harmful, racist, or sexist

### B. Search queries

The following is the set of search queries used to mine candidate images from the LAION [47] dataset during the data mining process of our system. All these search queries are generated using the LLM (PaLM-2 [2]) and encoded

in joint CLIP [43] embedding space to retrieve candidate images.

**Arts and crafts:** craft room, crafts book, crafts for beginners, crafts tutorial, arts and crafts, craft store, crafts fair, craft project, crafts for sale, crafts, crafts for kids, art, craftsmanship, craft supplies, diy, crafts magazine, crafts for adults, handmade

**Astronaut:** astronaut, astronaut in space station module, astronaut in space gloves, astronaut in space boots, astronaut in space flag, astronaut in space shuttle cockpit, astronaut in space suit, astronaut in orbit, astronaut in space backpack, astronaut in space station airlock, astronaut on moon, astronaut working in space, astronaut in space station, astronaut in space, astronaut in space helmet, astronaut in space shuttle, astronaut in space station cupola, astronaut walking in space

**Block tower:** tower of blocks, lego tower, tall lego tower, tall toy tower, tower of legos, tower of toys, towering wood, towering toys, towering blocks, block tower, towering legos, tall block tower, tower made of blocks, tall wooden tower, wooden tower, toy tower, tower of wood

**Dance:** street dance, flamenco, ballet, modern dance, bachata, ballroom dance, zouk, samba, people dancing, belly dance, salsa, merengue, dance performance, line dance, tap dance, hip hop, dancers, folk dance

**Emergency service:** police emergency, police officer at work, rescue boat, emergency response, police car, fire truck, rescue worker at work, emergency worker, medical emergency, firefighter, paramedic at work, rescue team, fire rescue, police, emergency service, rescue operation, firefighter at work, rescue helicopter, emergency vehicle, ambulance, paramedic

**Gourmet tuna:** tuna sushi, tuna sashimi, tuna salad, seared tuna, ahi tuna, gourmet tuna, tuna tartare, ahi tuna steak, tuna steak, fancy tuna

**Hand pointing:** hand pointing finger extended, hand pointing finger, hand pointing, hand pointing finger straight at them, hand pointing finger straight at someone, hand pointing finger straight at screen, hand index finger extended, hand pointing finger straight at something, hand pointing finger straight at person, hand pointing finger straight at me, hand pointing finger straight at us, hand pointing finger straight at you, hand pointing at screen, hand pointing finger straight at thing, hand pointing screen, hand pointing finger straight at object, hand pointing finger straight

**Hair coloring:** hair coloring, hair color salon, hair color before and after, hair color inspiration, hair color horror story, hair color mishap, hair color tutorial, hair color tips, hair dye, hair color stylist, hair color fail, hair color at home, hair color process, hair color mistake, hair color disaster, hair color gone wrong, hair color ideas, hair color, hair color gone bad

**Healthy dish:** healthy lunch, healthy sandwich, healthy

dish, healthy burger, healthy meal, healthy food, low carb dish, healthy salad, healthy fish, healthy pizza, healthy dinner, healthy vegetarian, healthy vegan, healthy snack, healthy breakfast, healthy pasta, healthy chicken, healthy soup, healthy dessert

**Home fragrance:** home fragrance, home fragrance diffuser, scented candle, home scented candle, home scent, essential oil, home air freshener, air freshener, home essential oil, home scent diffuser, home room spray, home aroma diffuser, home smell diffuser, home perfume, home aroma, fragrance diffuser, home smell, room spray

**In ear headphones:** earphone, in ear headphones, in ear headphone, earbuds, in ear, headphone

**Pie chart:** pie chart maker, pie chart data, pie chart tutorial, pie chart percentage, pie chart illustration, pie chart design, pie chart template, pie chart chart, pie chart, pie chart infographic, pie chart graphic, pie chart diagram, pie chart creator, pie chart graph, pie chart example, pie chart generator, pie chart tool, pie chart software

**Single sneaker on white background:** sneaker on light beige background, sneaker on beige background, sneaker on neutral, sneaker on light background, sneaker on cream background, single sneaker, sneaker on white background, sneaker, sneaker on background, sneaker on solid background, sneaker on light off-white background, sneaker on light tan background, sneaker on neutral background, sneaker on light gray background, sneaker on light cream background, sneaker on plain background, sneaker on off-white background, shoe, sneaker on tan background, sneaker on white, sneaker on gray background

**Stop sign:** stop sign on road, stop sign on street, held stop sign, stop sign held by person, traffic stop sign, stop sign in traffic, stop sign in city, stop sign on interstate, stop sign, stop sign on highway, construction stop sign, stop sign in construction, real stop sign, stop sign on freeway, stop sign in rural area, official stop sign, stop sign in parking lot, stop sign in hand

## C. LLM Prompts

We list a set of example prompts used in Modeling Collaborator Annotator below. When a description is unavailable for a given concept, we use the following prompt to auto-generate a structured description:

You are given a visual concept name.

Follow these steps:

```
<step1>You have to work as an expert
  → linguist. There are some human
  → annotators who need to determine
  → if given images are in-scope or
  → out-of-scope for this visual
  → concept. Your task is to generate
```

```

    ↪ description of the visual
    ↪ concept which annotators can use
    ↪ to decide if any images are in-
    ↪ scope or out-of-scope for the
    ↪ given visual concept.</step1>
<step2>Provide an concept definition of
    ↪ this visual image in a few
    ↪ sentences.</step2>
<step3>Provide all the image attributes
    ↪ that an image must have in order
    ↪ to be in-scope for this visual
    ↪ concept.</step3>
<step4>Each attribute found in step2
    ↪ and step3 should be verbose,
    ↪ independent, self-explanatory and
    ↪ meaningful.</step4>
<step7>Write your response in following
    ↪ user friendly and readable
    ↪ format:
Visual concept definition:
<Add 2-3 line concept definition of the
    ↪ visual concept here.>

```

```

Image must have following attributes
    ↪ for it to be in-scope for this
    ↪ visual concept:
<Add details here as bullet points.>
</step7>
<visualConceptName>{CONCEPT_NAME}</
    ↪ visualConceptName>

```

The prompt for generating positive search queries based on a visual concept (used to fetch candidate positive images from an image database):

```

Your task is to help in finding
    ↪ positive (in-scope) images for a
    ↪ visual concept. You are given the
    ↪ name and the description of a
    ↪ visual concept. Description
    ↪ explains the attributes of an
    ↪ image that make it in-scope for
    ↪ this visual concept. It also
    ↪ explains the attributes of an
    ↪ image that make it out-of-scope
    ↪ for this visual concept.

```

Follow these steps:

```

<step1>List all the attributes of an
    ↪ image that make it in-scope for
    ↪ this visual concept.</step1>
<step2>Each attribute should be
    ↪ objective, complete, and self-
    ↪ explanatory.</step2>

```

```

<step3>Ensure that attributes you have
    ↪ found cover all the in-scope
    ↪ attributes or scenarios mentioned
    ↪ in the description. If not, add
    ↪ the missing in-scope attributes
    ↪ .</step3>
<step4>Based on all the in-scope
    ↪ attributes you have identified in
    ↪ step3, generate 20 Google Search
    ↪ keywords which can be used to do
    ↪ Google image search for finding
    ↪ diverse images with those in-
    ↪ scope attributes.</step4>
<step5>Ensure that your Google Search
    ↪ keywords cover all types of in-
    ↪ scope images mentioned in the
    ↪ description. If not, add Google
    ↪ Search keywords to find those
    ↪ types of in-scope images.</step5>
<step6>This is an important step. Some
    ↪ of the keywords you selected so
    ↪ far could be be suitable for
    ↪ searching out-of-scope images.
    ↪ Identify those keywords which are
    ↪ for searching out-of-scope image
    ↪ . Remove those Google Search
    ↪ keywords from your response.</
    ↪ step6>
<step7>Each search query should be 3-4
    ↪ words long, independent, self-
    ↪ explanatory and meaningful for
    ↪ internet image search.</step7>
<step8>If any of these queries are
    ↪ longer than 4 words, summarize
    ↪ them into 3-4 words.</step8>
<step9>Write your response in following
    ↪ xml format. Since your response
    ↪ will be programmatically parsed,
    ↪ your response should strictly
    ↪ follow this format:
    ```xml
    <google_search_keywords>
      <keyword></keyword>
      ...
    </google_search_keywords>
    ```
</step9>
<step10>Keep only xml in the response
    ↪ and remove other text.</step10>
<concept>{CONCEPT_NAME}</concept>
<description>{CONCEPT_DESCRIPTION}</
    ↪ description>

```

The prompt for generating negative search queries based on a visual concept (used to fetch hard negative images from an image database):

You have to work as an expert linguist.  
↪ You are given a visual concept  
↪ name and its description for the  
↪ purpose of image classification.  
Description might contains few carve-  
↪ outs. Carve-outs are some special  
↪ situations in which images  
↪ should be classified as out-of-  
↪ scope. Your task is to extract  
↪ carve-out details from the  
↪ description.

Follow these steps:

```
<step1>If the description does not  
↪ contain any carve-outs, write  
↪ your response in the following  
↪ format and skip all of the  
↪ following steps.  
```xml  
<carveOutsInDescription>  
  <carveOut>NOT_FOUND</carveOut>  
</carveOutsInDescription>  
```  
</step1>  
<step2>If the description provides  
↪ details on out-of-scope images  
↪ for this visual concept, output  
↪ the list of those carve-outs  
↪ situations mentioned.</step2>  
<step3>Output those in the following  
↪ xml format. Since your response  
↪ will be programmatically parsed,  
↪ your response should strictly  
↪ follow this format:  
```xml  
<carveOutsInDescription>  
  <carveOut></carveOut>  
  ...  
</carveOutsInDescription>  
```  
</step3>  
<step4>Keep only xml in the response  
↪ and remove other text.</step4>  
  
<concept>{CONCEPT_NAME}</concept>  
<description>{CONCEPT_DESCRIPTION}</  
↪ description>
```

The prompt template for generating a concept's positive attributes:

Your task is to understand the scope of  
↪ a visual concept for image  
↪ classification. You are given a  
↪ visual concept name and its  
↪ description.

Description explains the attributes of  
↪ an image that make it in-scope  
↪ for this visual concept. It also  
↪ explains the attributes of an  
↪ image that make it out-of-scope  
↪ for this visual concept.

Follow these steps:

```
<step1>List all the attributes of an  
↪ image that make it in-scope for  
↪ this visual concept.</step1>  
  
<step2>Each attribute should be  
↪ objective, unambiguous, detailed,  
↪ verbose and self-explanatory.</  
↪ step2>  
  
<step3>Check that attributes you have  
↪ found cover all the positive  
↪ attributes mentioned in the  
↪ description. If not, add the  
↪ missing attributes.</step3>  
  
<step4>Write your response in following  
↪ xml format. Since your response  
↪ will be programmatically parsed,  
↪ your response should strictly  
↪ follow this format:  
  
```xml  
<positiveAttributes>  
  <attribute></attribute>  
  ...  
</positiveAttributes>  
```  
</step4>  
<step5>Keep only xml in the response  
↪ and remove other text.</step5>  
<concept>{CONCEPT_NAME}</concept>  
<description>{CONCEPT_DESCRIPTION}</  
↪ description>
```

The prompt template for generating a concept's negative attributes:

You have to work as an expert linguist.  
↪ You are given a visual concept

- ↪ name and its description for the
- ↪ purpose of image classification.

Description might contains few carve-

- ↪ outs. Carve-outs are some special
- ↪ situations in which images
- ↪ should be classified as out-of-
- ↪ scope. Your task is to extract
- ↪ carve-out details from the
- ↪ description.

Follow these steps:

```
<step1>If the description does not
  ↪ contain any carve-outs, write
  ↪ your response in the following
  ↪ format and skip all of the
  ↪ following steps.
```

```
```xml
<carveOutsInDescription>
  <carveOut>NOT_FOUND</carveOut>
</carveOutsInDescription>
```
</step1>
<step2>If the description provides
  ↪ details on out-of-scope images
  ↪ for this visual concept, output
  ↪ the list of those carve-outs
  ↪ situations mentioned.</step2>
<step3>Output those in the following
  ↪ xml format. Since your response
  ↪ will be programmatically parsed,
  ↪ your response should strictly
  ↪ follow this format:
```

```
```xml
<carveOutsInDescription>
  <carveOut></carveOut>
  ...
</carveOutsInDescription>
```
</step3>
<step4>Keep only xml in the response
  ↪ and remove other text.</step4>
```

```
<concept>{CONCEPT_NAME}</concept>
<description>{CONCEPT_DESCRIPTION}</
  ↪ description>
```

where CONCEPT\_NAME and CONCEPT\_DESCRIPTION are the subjective concept name and description.

For a final annotation decision for an image, we feed the following prompt to PaLM-2:

```
You are given the name and description
  ↪ of a visual concept. We showed
  ↪ the image to raters and asked
```

- ↪ many questions about the image
- ↪ and they gave the answers.
- ↪ Questions and answers are also
- ↪ provided below. Your task is to
- ↪ answer some questions about the
- ↪ image. Follow these steps:

```
<step1>In the following steps, your
  ↪ text responses must be strictly
  ↪ based on the answers provided in
  ↪ raters' responses.</step1>
```

```
<step2>Provide the out-of-scope
  ↪ attributes present in the image
  ↪ .</step2>
```

```
<step3>Provide the in-scope attributes
  ↪ present in the image.</step3>
```

```
<step4>Provide the the in-scope
  ↪ attributes missing in the image
  ↪ .</step4>
```

```
<step5>Classify the image based on the
  ↪ following rules. Rules must be
  ↪ followed in the given order.
```

```
<classificationRules>
<rule1>If the image has EVEN ONE of
  ↪ the out-of-scope attributes, it
  ↪ must be classified negative for
  ↪ this visual concept.</rule1>
<rule2>The image must have all the
  ↪ required positive attributes to
  ↪ classify the image as positive
  ↪ for this visual concept. If
  ↪ image has all the required
  ↪ positive attributes, classify the
  ↪ image as positive. Otherwise
  ↪ classify it as negative.</rule2>
```

```
<rule3>In all other cases, classify the
  ↪ image as negative.</rule3>
</classificationRules></step5>
```

```
<step6>Add following details to your
  ↪ response strictly in this format:
Decision: "Positive" or "Negative"
Reasons: <Provide list of reasons why
  ↪ this image is Positive or
  ↪ Negative> </step6>
```

```
<step7>Make sure your response only
  ↳ contains text and no python code
  ↳ .</step7>
```

```
<concept>{CONCEPT_NAME}</concept>
<conceptDescription>{
  ↳ CONCEPT_DESCRIPTION}</
  ↳ conceptDescription>
<raterResponses>{
  ↳ PALI_QUESTIONS_AND_ANSWERS}</
  ↳ raterResponses>
```

where PALI\_QUESTIONS\_AND\_ANSWERS is a formatted string of questions fed to PaLI-X VQA and their respective answers.

### D. Ablations

To measure the effect of the expert involvement we show Fig. 6. Overall, expert collaboration improves the performance of the distilled model. As the number of expert-labeled examples increases (0 to 2000 out of total training 4000 examples), the recall, F1, and auPR scores of the model also increase.

To show the impact of additional automatically annotated data on the performance of the final output model on easy vs hard concepts, we show Fig. 5.

### E. Annotator Configurations

We define the following settings for the Annotator:

- A. `use_positive_attributes_for_questions`: Whether to generate positive questions from the attributes or directly from the concept description.
- B. `generate_negative_questions`: Whether or not to generate negative questions. Sometimes these questions result in over-predicting negative classes.
- C. `use_captioning_questions`: Whether to use a captioning VLM to generate a detailed description of the image
- D. `generate_fixed_num_of_questions`: Fix the number of questions instead of having the LLM generate as many questions as possible.
- E. `final_rating_without_attributes`: Whether to use negative and positive attribute in the final annotation stage.

Using a grid search, we use different configurations for different concept as described in Tab. 4.

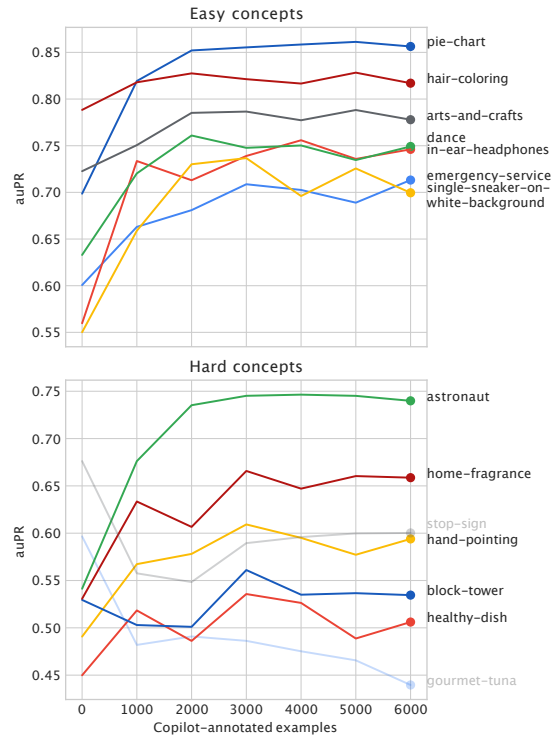


Figure 5. The impact of adding additional automatically annotated images on the final model quality (using the auPR metric). 100 user-annotated examples are used in addition to the thousands of Modeling Collaborator examples.

Concept	Configuration				
	A	B	C	D	E
arts-and-crafts				✓	✓
astronaut			✓	✓	✓
block-tower			✓	✓	✓
dance			✓	✓	✓
emergency-service					✓
gourmet-tuna				✓	✓
hair-coloring					✓
hand-pointing					✓
healthy-dish			✓	✓	✓
home-fragrance				✓	✓
in-ear-headphones			✓	✓	✓
pie-chart			✓	✓	✓
single-sneaker				✓	✓
stop-sign				✓	✓

Table 4. Configuration settings used for each concept of the Agile Modeling [51] dataset.





Figure 6. The impact of Modeling Collaborator and expert collaboration on the performance of the distilled model. 4,000 total training examples were used per concept. The x-axis represents how many of those examples were labeled by the expert (concept owner), ranging from no examples (0%) to 2,000 examples (50%).