Perhaps PTLMs should go to School – A Task to Assess Open Book and Closed Book QA

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Abstract

Our goal is to deliver a new task and leaderboard to stimulate research on question answering and pre-trained language models (PTLMs) to understand a significant instructional document, e.g., an introductory college textbook or a manual. PTLMs have shown significant success in many question-answering tasks, given significant supervised training for the task, but much less so in zero-shot settings. The task includes two introductory college texts in the social sciences (American Government 2e) and humanities (U.S. History), hundreds of true-false questions based on review questions written by the textbook authors, validation/development tests based on the first eight chapters of the textbooks, blind tests based on the remaining textbook chapters, and baseline results given state-of-the-art PTLMs.

Since the questions are balanced, random performance should be ~50%. T5, fine-tuned with BoolQ, is only slightly better, suggesting that the textbook's content is not pre-represented in the PTLM. Taking the exam closed book, but having read the textbook (i.e., adding the textbook to T5's pre-training), yields at best minor improvement (56%), suggesting that the PTLM may not have "understood" the textbook (or perhaps misunderstood the questions). Performance is better (~60%) when the exam is taken open-book (i.e., allowing the machine to automatically retrieve a paragraph and use it to answer the question).

1 Introduction

Question answering (QA) is a yardstick for measuring machine understanding performance (Hermann et al., 2015). QA's popularity as an evaluation technique has led to several sub-categories: tasks can require a model to answer questions from either its background knowledge or from a short passage (e.g., SQuAD, Rajpurkar et al. (2016)) or with information retrieval to allow the model to search for the answer in a large corpus (e.g., ARC, Clark et al. (2018)). Answering can take the form of true/false classification (BoolQ, Clark et al. (2019)), multiple-choice, span selection (SQuAD, Rajpurkar et al. (2016)), or text generation (TriviaQA, Joshi et al. (2017)).

Transformer architectures optimized for specific QA formulations have driven recent progress in question answering. For example, some models target IR-oriented QA (Guu et al., 2020) while others optimize their learning strategy to specific question types (e.g., by optimizing for expected answers to factoid questions, Roberts et al. (2020)). While specialization improves performance, it limits generalization. UnifiedQA (Khashabi et al., 2020) takes a step forward by generalizing the architecture and training over multiple data sets with different QA formulations.

Most research assumes that the information necessary to answer questions is either included with the query (e.g., BoolQ, SQuAD 1.1) or that the information was already stored in language models either during initial pre-training or during a task-specific second pre-training.[1] However, this assumption is a limitation for language models relying on massive corpora (Raffel et al., 2020; Gao et al., 2020) to learn oft-repeated facts (Petroni et al., 2019). Valuable, domain-specific information seldom is repeated often enough to be captured by language models. An evaluation of domain-specific knowledge without access to a relevant text is even more challenging as simple strategies like identifying the answer by information retrieval are ineffective. Even reasoning tasks such as ARC (Clark et al., 2018) only target general scientific knowledge and offer large text corpora to aid QA systems.

We propose Learning from Textbooks (LEFT), a new task where systems must classify domain-

[1] For example, Roberts et al. (2020) adjust T5's masking strategy to target named entities as they expect named entities to be parts of answers.

specific statements drawn from a textbook's review questions as true or false. We define three test configurations for a model. The first tests models' ability to answer questions without any domain-specific material (e.g., applying a PTLM with no access to domain-specific knowledge). This setting is equivalent to a person taking the test before taking the class. In the second configuration, a model has access the textbook's content and may encode the information in the textbook but may not access the textbook during the test; we call this *closed book*. The second setting tests a model's ability to learn by reading. In the third configuration, which we call *open book*, models can access the textbook during the test. Thus, LEFT supports contrasting QA formulations and reading methods to explore the strengths and weaknesses of various QA approaches.

2 Related Work

Question Answering. Most previous research specializes QA models to target specific question formulations. Question answering with a relevant paragraph often relies on span selection (Yang et al., 2015; Rajpurkar et al., 2016) or simple reasoning (Clark et al., 2019). Previous open-book QA methods first filter a large corpus to a small set of relevant documents using information retrieval (Robertson and Zaragoza, 2009; Karpukhin et al., 2020). The document set then provides context for answering questions (Joshi et al., 2017; Nguyen et al., 2016; Dhingra et al., 2017; Dunn et al., 2017). Conversely, closed-book QA instead requires models to answer using only their implicit knowledge (Roberts et al., 2020). Taking a step towards generalizing QA, UnifiedQA (Khashabi et al., 2020) proposes a unified architecture that answers various question types relying partly on knowledge encoded in its language model.

Knowledge in Pre-trained Language Models. Pre-trained language models (PTLMs) have shown good performance in cloze-style queries (Petroni et al., 2019), fact-checking (Thorne et al., 2018), entity linking (Hoffart et al., 2011; Guo and Barbosa, 2018), and open-domain QA (Kwiatkowski et al., 2019; Joshi et al., 2017; Petroni et al., 2020). However, in most cases, the PTLMs rely on knowledge learned from massive corpora during pre-training. LEFT tests domain-specific knowledge acquired from a textbook, a small corpus of only a few hundreds of thousands of words (see Table 1).

	AG		USH		
	Dev	Test	Dev	Dev+	Test
Num. chapters	8	9	8	8	24
Text size (words)	137 620	138 669	89 765	89 765	301 860
Num. statements	186	214	148	376	412

Table 1: Data overview for the two textbooks: American Government 2e (AG) and U.S. History (USH). The *Dev+* set consists of the *Dev* set and the statements based on questions from a community of instructors.

Textbook Question Answering. Researchers have explored machine understanding of elementary and middle-school science textbooks by visual question answering (Kembhavi et al., 2017; Kim et al., 2019; Gomez-Perez and Ortega, 2020) and information retrieval (Clark et al., 2018). While existing textbook QA tasks focus on general knowledge (which can be gained by pre-training on general web corpora), LEFT focuses on domain-specific knowledge. Furthermore, it quantifies pre-trained language models' pre-existing knowledge by requiring that models take the task *before* and *after* reading LEFT's corpus.

3 Task Description

Learning from Textbooks (LEFT) contains two machine-readable textbooks at the introductory college level and a set of true or false statements manually derived from review questions written by the textbook authors. The task requires that systems based on language models classify the statements *before* and *after* reading the given textbook material to separate what was learned from the book from what was known before reading. "Reading" is any algorithm method that learns from the domain text without storing a copy of the text. To support comparisons with existing QA approaches, LEFT also supports the open-book setting, where a system can use a textbook paragraph when answering.

Our goal is to support testing pre-trained language models, e.g., T5 (Raffel et al., 2020), and also those approaches that extract and store triples during reading (e.g., <*US Declaration of independence, signed, Aug 2, 1776*>). While learning corpora appear in other question answering tasks (e.g., ARC, 14M words, Clark et al. (2018)), the text included in LEFT is small and corresponds to the textbook chapters relevant to each question set. The largest text in LEFT contains only 300K words (for details, see Table 1).

LEFT includes two open-license[2] college-level introductory textbooks, *American Government 2e* (Krutz, 2019) and *U.S. History* (Corbett, 2014), and true/false statements derived from each book's review questions. We manually rewrote each textbook's multiple-choice review questions into a balanced set of true and false statements.[3,4] We intentionally wrote the statements such that each *true* and *false* pair has high word overlap to deter classification strategies that rely on word overlap with the textbook. We include five sample statements from LEFT in Appendix A.

We measure task performance by *accuracy*. Since the two textbooks are used in teaching college students, we do not release the correct labels (see the Ethical Considerations section). We split each textbook into a *Dev* set consisting of the first eight chapters and a *Test* set consisting of the remaining chapters (see Table 1 for an overview). We allow unlimited submissions to the *Dev* set, but for any submission, we only provide the overall *accuracy* without feedback on which statements were correctly classified. This design decision aims to prevent divulging the correct answers (see the Ethical Considerations section).

We require that all submissions to LEFT's closed-book assessment contain predictions *before* and *after* reading the textbook material. Predictions *before* reading quantify the information included in each model through initial pre-training. The change in performance *after* reading illustrates each model's reading effectiveness.

4 Results

We illustrate baseline performance on LEFT using two state-of-the-art language models: T5 (Raffel et al., 2020) and GPT-Neo (a GPT-3 architecture, Brown et al. (2020), trained on the open Pile corpus (Gao et al., 2020)). We fine-tune the two language models using BoolQ (Clark et al., 2019). Table 2 shows results in LEFT's three evaluation settings: **Prior-knowledge** (out-of-the-box language models fine-tuned on BoolQ), **Closed-book, after reading** (language models with continued light pre-training on LEFT's text content), and **Open-book** (where models have access to the relevant textbook paragraph). Since the Prior knowledge and Closed-book settings do not include the relevant paragraph for each question, we adjust fine-tuning to only use BoolQ's questions and ignore its text snippets. In the Open-book setting, we consider automatically retrieved textbook paragraphs (using sBERT, Reimers and Gurevych (2019)) and manually identified the relevant paragraphs (gold information retrieval, goldIR). When selecting the relevant textbook content, a snippet matches a paragraph exactly as written by each textbook's authors. However, due to technical limitations imposed by T5's memory consumption, in our experiments, we limit the concatenated statements and paragraphs to a maximum length of 128 word pieces (see Appendix B.1).

4.1 Baseline Results

T5 and GPT-Neo's scores are indistinguishable from the random baseline of 50% in the *Prior-knowledge setting*, suggesting that the textbooks query for information is *not* already present in the two language models. Continuing each model's pre-training with the relevant textbook parts sometimes helps, but not consistently. The lack of improvement *after* reading is further evidence that the models memorize, but not in particularly useful ways, i.e., they can complete sentences but did not learn the subject matter and cannot classify the statements, even after 20 epochs. It also suggests that the closed-book setting represents a new challenge for PTLMs.

Accuracy in the open-book setting is far higher, especially when using goldIR (i.e., a manually selected relevant paragraph). As in the closed book setting, we contrast models using only prior knowledge with models pre-trained on the textbook. Pre-training with the textbook never improves the system's accuracy — suggesting that even in this setting, the models are not learning by reading the textbook. The gap between goldIR- and sBERT-based retrieval suggests that there is room for retrieval-based improvement in the open-book setting. However, even with goldIR, T5 only achieves an accuracy of ~70%, suggesting that paragraph-based QA alone is not solved with existing models.

[2]Both textbooks are licensed under the Creative Commons Attribution License v4.0 license.

[3]We construct one true and one false statement for each question to obtain a balanced data set. For example, the question *When was the US Declaration of Independence signed? (A)(correct) August 2, 1776 (B) December 2, 1776, (C) August 2, 1746, (D) August 22, 1976* could become *The US Declaration of Independence was signed on August 2, 1776* (true) and *The US Declaration of Independence was signed on August 2, 1746* (false).

[4]For U.S. History, we also process questions written by a community of instructors to obtain a second set of true/false statements.

	American Government 2e		U.S. History		
	Dev (186)	Test (214)	Dev (148)	Dev+ (376)	Test (412)
Prior-knowledge					
T5-3B -ctx	51.07	49.53	50.00	50.00	50.00
GPT-Neo 2.7B -ctx	52.68	48.13	51.35	50.27	49.75
Closed-book, after reading					
T5 3B +pt -ctx	56.45	52.33	49.32	49.73	48.79
GPT-Neo 2.7B +pt -ctx	50.00	55.14	50.67	50.80	49.75
Open-book					
T5-3B +ctx +sBERT	59.13	60.74	53.37	**56.38**	**59.46**
T5-3B +pt +ctx +sBERT	60.21	57.94	51.35	50.53	55.58
T5-3B +ctx +goldIR	**70.96**	**74.30**	**69.59**	-	-
T5-3B +pt +ctx +goldIR	66.12	63.08	61.48	-	-

Table 2: Baseline accuracy with the current state-of-the-art language models. The *Dev+* set consists of the *Dev* set and the statements based on questions from a community of instructors. In the heading, each set's name is followed by its number of statements. The order of abbreviations reflects the order of operations. All models are fine-tuned with BoolQ; *+/- ctx* – whether we included BoolQ's context during fine-tuning; *+pt* – whether we pre-trained on the relevant textbook chapters. Fields marked with a "-" correspond to sets for which we do not yet have goldIR and are addressed in Section 5.

5 Conclusions & Future Work

There are several natural directions in which we can extend and improve LEFT. We plan to set up a web-based leaderboard to support easy, automated evaluation on LEFT after this paper's publication. Secondly, since manually-collected relevant paragraphs allow researchers to decouple information retrieval and context-based question-answering in the open-book setting, we are collecting relevant paragraphs for all sets in Table 2. We are extending U.S. History's *Test* set similarly to the *Dev+* set by including statements based on questions written by a community of instructors. Lastly, we are categorizing the kind of knowledge required to classify each statement to better understand what kinds of knowledge pose the most difficulties.

We draw several conclusions from this work. Foremost, Learning from Textbooks (LEFT) represents a new type of challenge task for PTLMs, contrasted with the much-studied challenges of (1) common sense QA based on prior knowledge, (2) reading comprehension given a paragraph, and (3) knowledge specific to a field, e.g., science at the elementary or middle school level. The task is intended to stimulate research on the following dimensions:

1. Zero-shot learning, much as an entering college student could do when studying a textbook,

2. Measuring a system's knowledge before vs. after "reading" the textbook,

3. Capability in both closed-book and open-book question answering,

4. The effect of IR accuracy on task accuracy compared to the system's language understanding performance.

Our baseline studies show that T5 and GPT-Neo thus far are challenged to show improvement after reading the relevant textbook, that open-book evaluation is easier than closed-book (as it is for humans), and that the gating factor in LEFT is understanding the textbook and/or the question rather than paragraph retrieval. The baseline results show there is much room for improvement.

Ethical Considerations

We have considered two kinds of ethical considerations when creating Learning from Textbooks (LEFT): content and environmental aspects.

Content. The two textbooks in LEFT cover topics that include history, race, and politics. OpenStax textbooks follow a set of *Diversity and Representation Development Guidelines* which aim to "properly represent genders, gender identities, races, cultures, geographies, ethnic backgrounds, disabilities, nationalities, ages, sexual orientations, socioeconomic status, and diverse viewpoints".[5] As creators of an NLP task, we do not make any claims, nor do we comment on the topics covered in the two textbooks. Furthermore, we understand that

[5]See *Diversity and Representation Development Guidelines* in the instructor materials for each textbook.

documents as large and complex as textbooks are bound to contain inaccuracies. We invite users with specific content accuracy concerns to consult the official textbook errata included in each textbook's instructor resources.[6]

Releasing labels for the statements in LEFT would indirectly reveal the correct answers for multiple-choice questions in the two textbooks. While both American Government 2e and U.S. History include answer keys, they are incomplete. We believe releasing the correct answers to all multiple-choice questions in the book would be detrimental to the intended primary users of the two textbooks; in other words, it might hinder students' learning. We only used full-time employees compensated according to US law to rewrite the multiple-choice review questions in the two textbooks.

Environmental. We included baseline results based on large pre-trained language models. Strubell et al. (2019) concerns about the environmental impact of training deep learning language models. As pointed out by Patterson et al. (2021), most of the energy consumption for deep learning language models comes during the initial pre-training. In this work, we limit ourselves to fine-tuning and light continued pre-training of T5 and GPT-Neo. While we do not have information about GPT-Neo's training, T5's training took place in highly efficient data centers whose energy consumption was offset by purchasing electricity from renewable sources (Patterson et al., 2021). For our light pre-training and fine-tuning, we use a machine with four NVIDIA Quadro RTX 8000 fed from *Anonymized Location*'s energy grid. Our total computation time for the experiments in this paper is about 500 hours, but this is an informal estimate rather than an accurate measurement.

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[6] See the *Errata Release Notes* at https://openstax.org/details/books/american-government-2e?Instructor%20resources for *American Government 2e* and https://openstax.org/details/books/us-history?Instructor%20resources for *U.S. History*.

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A Sample statements

Sample statements in LEFT. The first two statements are from American Government 2e, the following three from U.S. History:

- Public goods are available to all without payment.
- In a majoritarian voting electoral system voters select the party of their choice rather than an individual candidate.
- Europeans did not introduce Indians to wampum.
- Philadelphia served as the base for British operations for most of the Revolutionary War.
- The British bombardment of Baltimore inspired The Star-Spangled Banner.

B Training details

For all light pre-training and fine-tuning, we use a machine with four NVIDIA Quadro RTX 8000 GPUs.

B.1 T5-3B

We implement the model using PyTorch Lightning (et al., 2019) and Hugging Face's PyTorch Transformers (Wolf et al., 2020). For pre-training and fine-tuning, we a maximum sequence length 128. We searched for the best learning rate for our model out of $\{3e-5, 1e-4, 3e-4, 1e-3\}$.

	Fine-tuning	Pre-training
Batch size	16	16
Gradient accumulation	1	1
Learning Rate	3e-4	1e-3
Num epochs	20	
Optimizer	AdamW	
$\beta 1$	0.9	
$\beta 2$	0.999	
ϵ	1e-8	
Weight decay	0.0	
Scheduler	WarmupDecayLR	
Warmup max steps	400	
fp16	no	

Table 3: Hyperparameters for T5-3B.

B.2 GPT-Neo 2.7B

We use GPT-Neo 2.7B from the Hugging Face Model Hub.[7] GPT-Neo matches the architecture of GPT-3 (Brown et al., 2020), but is trained on the openly available Pile corpus (Gao et al., 2020).

	Fine-tuning	Pre-training
Batch size	48	2
Gradient accumulation	1	4
Num epochs	10	
Optimizer	AdamW	
$\beta 1$	0.9	
$\beta 2$	0.999	
ϵ	1e-8	
Weight decay	0.01	
Scheduler	WarmupDecayLR	
Warmup max steps	200	
fp16	yes	

Table 4: Hyperparameters for GPT-Neo.

[7] https://huggingface.co/EleutherAI/gpt-neo-2.7B