MixQG: Neural Question Generation with Mixed Answer Types

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Abstract

Asking good questions is an essential ability for both human and machine intelligence. However, existing neural question generation approaches mainly focus on short factoid type of answers. In this paper, we introduce a neural question generator, MixQG, to bridge this gap. We combine nine question answering datasets with diverse answer types, including yes/no, multiple-choice, extractive, and abstractive answers, to train a single generative model. We show with empirical results that our model outperforms existing work in both seen and unseen domains, and can generate questions with different cognitive levels when conditioned on different answer types. We run a human evaluation study to assess the quality of generated questions and find that MixQG outperforms the next best model by 10%. Our code and model checkpoints will be released and integrated with the HuggingFace library to facilitate various downstream applications.

Context: In the late 17th century, Robert Boyle proved that air is necessary for combustion. English chemist John Mayow (1641–1679) refined this work by showing that fire requires only a part of air that he called spiritus nitroaereus or just nitroaereus. In one experiment he found that placing either a mouse or a lit candle in a closed container over water caused the water to rise and replace one-fourteenth of the air's volume before extinguishing the subjects. From this he surmised that nitroaereus is consumed in both respiration and combustion.

Question: Who proved that air is necessary for combustion?
Ext. Short Answer: Robert Boyle

Question: How did John Mayow find that spiritus nitroaereus is consumed in both respiration and combustion?
Abs. Short Answer: through an experiment

Question: Does fire need air to burn?
Yes/No Answer: yes

Question: What did John Mayow discover about nitroaereus?
Ext. Long Answer: In the late 17th century . . . in both respiration and combustion.

Question: Why was the mouse used in the experiment?
Abs. Long Answer: The mouse was used in the experiment to test the consumption of nitroaereus during respiration.

Figure 1: Given the same context, MixQG generates diverse questions based on the target answer choice.

1 Introduction

Question generation (QG) aims to automatically create questions from a given text passage or document with or without answers. It has a wide range of applications such as improving question answering (QA) systems (Duan et al., 2017) and search engines (Han et al., 2019) through data augmentation, making chatbots more engaging (Wang et al., 2018; Laban et al., 2020), enabling automatic evaluation (Rebuffel et al., 2021) and fact verification (Pan et al., 2021), and facilitating educational applications (Chen et al., 2018).

Earlier QG approaches relied on syntactic rules that incorporated linguistic features into the QG process (Heilman and Smith, 2010; Khullar et al., 2018). Du et al. (2017) pointed out some of the limitations of such rule-based systems and formulated the task of question generation as a sequence-to-sequence learning problem. Based on this formulation, recent works rely on pre-trained Transformer-based models to generate answer-aware questions (Dong et al., 2019a; Yan et al., 2020a; Lelkes et al., 2021). However, the majority of QG research so far has been performed on the SQuAD dataset (Rajpurkar et al., 2016), and as a result, it mainly focuses on factoid short answer questions (Zhang and Bansal, 2019; Zhou et al., 2019; Su et al., 2020).

In reality, answers can come in a variety of types and forms, e.g., short/long, multiple-choice, yes-no, and extractive/abstractive answers. We hypothesize that *answer types are as important as question types*, and that different answer types have their unique QG challenges and result in questions with different cognitive levels. MixQG combines nine QA datasets with varied answer types to build a more robust and versatile QG model. We use pre-trained generative language models like T5 (Raffel et al., 2020) and BART (Lewis et al., 2019) without question-specific or domain-specific prefixes to generate the questions. Figure 1 illustrates the above, showing MixQG-generated questions of different cognitive levels for different answer types.

The contribution of this paper is summarized as follows: 1) We train a unified QG model that achieves state-of-the-art performance in both seen and unseen domains. We release training code and model checkpoints (base, large, 3B) to facilitate various downstream QG applications [1]. 2) We show that MixQG is able to produce different cognitive level questions by controlling the answer types. We conduct a human evaluation study which confirms that MixQG leads to improvements in question quality in a practical quiz design setting.

2 Methodology

2.1 Datasets

We leverage nine commonly used QA datasets (Table 3) to train our MixQG model, including six MRQA 2019 Shared Task (Fisch et al., 2019) datasets, NarrativeQA (Kočiský et al., 2018), MCTest (Richardson et al., 2013), and BoolQ (Clark et al., 2019). These represent the majority of large-scale publicly available QA datasets. We obtain in total 560,193 training examples with different answer types and source domains. We reserve their validation set for in-domain evaluation.

In most general sense, a QA dataset comprises of <C, Q, A> tuples, where C is a context document, Q is a human-written question, and A is its corresponding answer. Following a common classification of answer types, we bucket each dataset into one of the below categories: 1) **Extractive [EX]**: the answer to the question is a substring of the context passage. 2) **Abstractive [AB]**: the answer to the question is written in free-form and is not necessarily contained within the context passage. 3) **Multiple-Choice [MC]**: question comes with multiple answers to select from, including a single correct option and several distractors. 4) **Yes-No [YN]**: the answer is a boolean response.

We also leverage a set of datasets unseen during training to evaluate our model's generalization ability. Similar to the train datasets, these cover several text sources, domains, and answer types. Quoref (Dasigi et al., 2019) questions can have disjoint spans as answers and often require coreference resolution. DROP (Dua et al., 2019) questions require discrete reasoning over the context paragraphs. QAConv (Wu et al., 2021) uses informative conversations such as emails, channels, and panels as a knowledge source, and it includes extractive answers from multiple text spans.

Note that to generate fluent questions, we need to place some restrictions on the training data we use. For example, we disregard "fill-in-the-blank" (a.k.a Cloze-style) reading comprehension datasets as their questions are implicit and thus do not aid the QG model. Similarly, we ensure that our training data does not contain unanswerable questions or multiple-choice questions that are too general (e.g., "which of the following is TRUE according to the passage?").

Type	Input
EX	{answer} \n {context}
AB	{answer} \n {context}
MC	{correct_answer} \n {context}
YN	{answer} + {entities} \n {context}

Table 1: Input answer formatting.

2.2 Language Modeling

We rely on a text-to-text framework as a basis for MixQG (Training details are in Section A). When combining our training datasets, we encode all inputs and outputs into a unified plain-text format. For answer-aware question generation, the input is usually formatted in one of the two ways: (1) prepending (**-pre**) the answer before the context and separating it from the rest of the text by a special separator token or (2) highlighting (**-hl**) the answer span within the context with special highlight tokens (Chan and Fan, 2019). To maintain flexibility, we rely on prepending the answer since highlighting is only applicable to the extractive answer types. In particular, we format the inputs to our model such that the answer always precedes the context paragraph and use a "\n" separator in between, as shown in Table 1.

For MC type of data, we only take the correct answer and disregard the distractor options. For YN data, we extract entities from the question using spaCy's NER model [2] and append them to the answer. The reason for adding additional entities is to restrict the domain of questions, as given a context paragraph, there are many boolean questions whose answer would be yes or no, without further restriction. Note that no type-specific prefixes are added to the input representation, and the corresponding questions are used as output.

[1] www.anonymous.com

[2] https://spacy.io/api/entityrecognizer

Dataset	Model	Size	BLEU	R1	R2	RL	RLsum	METEOR	BERTScore
SQuAD	ProphetNet-pre	large	22.88	51.37	29.48	47.11	47.09	41.46	0.4931
	BART-hl	base	21.13	51.88	29.43	48.00	48.01	40.23	0.5433
	T5-hl	base	23.19	53.52	31.22	49.40	49.40	42.68	0.5548
	BART-pre	base	22.09	52.75	30.56	48.79	48.78	41.39	0.5486
	T5-pre	base	**23.74**	54.12	31.84	49.82	49.81	43.63	0.5568
	MixQG	base	23.53	54.39	32.06	50.05	50.02	43.83	0.5566
	MixQG$_{finetuned}$	base	23.46	**54.48**	**32.18**	**50.14**	**50.10**	**44.15**	**0.5582**
	MixQG	3B	**25.42**	**56.11**	**33.91**	**51.85**	**51.86**	**45.75**	**0.5789**
NQ	T5-pre	base	29.99	59.53	37.83	56.65	56.64	54.38	0.5202
	MixQG	base	30.69	60.04	38.43	57.09	57.09	54.76	0.5246
	MixQG$_{finetuned}$	base	**31.25**	**60.98**	**39.21**	**57.84**	**57.84**	**55.90**	**0.5351**
	MixQG	3B	**33.91**	**63.17**	**41.95**	**60.15**	**60.15**	**58.34**	**0.5610**
QAConv	T5-pre	base	21.32	45.94	27.91	42.92	42.90	38.27	0.4374
	MixQG	base	16.65	39.99	22.01	37.62	37.59	29.07	0.4117
	MixQG$_{finetuned}$	base	**22.74**	**47.40**	**29.48**	**44.41**	**44.40**	**39.93**	**0.4533**
Quoref	T5-pre	base	26.88	45.54	31.98	44.10	44.12	41.84	**0.4150**
	MixQG	base	4.28	24.89	7.97	22.27	22.30	14.13	0.2859
	MixQG$_{finetuned}$	base	**27.36**	**45.91**	**32.41**	**44.42**	**44.42**	**42.06**	0.4137
DROP	T5-pre	base	28.46	53.48	35.49	50.97	51.00	47.50	0.5491
	MixQG	base	7.16	30.66	12.95	28.38	28.40	23.23	0.3556
	MixQG$_{finetuned}$	base	**28.53**	**53.72**	**35.63**	**51.11**	**51.12**	**47.83**	**0.5493**

Table 2: Results on two seen datasets, SQuAD (Rajpurkar et al., 2016) and NQ (Kwiatkowski et al., 2019), and three unseen datasets, QAConv (Wu et al., 2021), Quoref (Dasigi et al., 2019), and DROP (Dua et al., 2019).

3 Experimental Results

3.1 Automatic Metrics

We report the commonly-used metrics applied in the QG research: BLEU (Papineni et al., 2002), ROUGE (Lin, 2004), and METEOR (Banerjee and Lavie, 2005) scores. We also report BERTScore (Zhang et al., 2020), which relies on contextual embeddings to produce the final score.

3.2 In-Domain Analysis

In Table 2, we compare baselines trained solely on the target in-domain dataset against MixQG and MixQG$_{finetuned}$. MixQG indicates our model that is joint trained on nine QA datasets with random sampling, and MixQG$_{finetuned}$ is the one further fine-tuned on the target dataset. We show results on two datasets: SQuAD and NQ. Since SQuAD is the most common benchmark for QG, we additionally compare MixQG against existing question generation models such as ProphetNet (Qi et al., 2020) and other T5 variants. The results show that MixQG outperforms an equally sized model trained directly on the target dataset. Given that question styles and dataset domains may vary across MixQG's seed datasets, additional fine-tuning on the target dataset further improves the scores. This shows that MixQG is a strong pretrained model which can be further adapted to specific use cases.

3.3 Out-of-Domain Analysis

We observe that a dedicated model trained on the target dataset outperforms MixQG in a zero-shot setting. One potential reason is that answer and question style in different QA datasets may differ significantly. For example, answers are ambiguous pronouns in the Quoref dataset, and questions in DROP dataset are intentionally created for discrete reasoning. However, MixQG$_{finetuned}$ obtains the best overall scores after further fine-tuning on the target training set, suggesting that MixQG is a strong starting point for further fine-tuning question generation models.

3.4 Human Evaluation

Recent studies have shown that n-gram based metrics may not correlate well with human judgements Nema and Khapra (2018). The objective of human evaluation is to evaluate QG models by measuring how useful they are as a tool to aid teachers in quiz creation. We compare seven QG models and collect 3,164 human-annotated samples from 10 recruited teachers. More details are in Section B.

Quiz Design Task Given an article on the quiz topic selected from Wikipedia, teachers are asked to specify a quiz concept (a subset of the article) they want to test their students on. This is used as the target answer input for QG models. Teachers can then approve a generated question to be in-

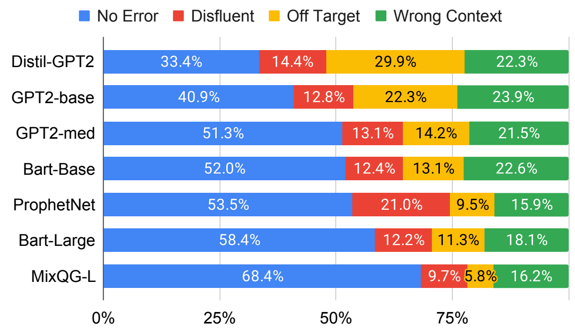

Figure 2: Human approval rate of seven QG models.

cluded on the quiz or reject it and provide a reason for rejection. The success of a QG model depends on its question approval rate.

Besides MixQG, three GPT2 baselines (Radford et al., 2019), two BART baselines (Lewis et al., 2019), and ProphetNet-Large finetuned on SQuAD are evaluated. In Figure 2, we see that MixQG attains a 68.4% acceptance rate, outperforming the next best model by 10%. MixQG also generates the smallest number of disfluent and off target (answer mismatch) questions - with majority of errors coming from wrong context (too general or too specific) questions. Generating questions with the right level of specificity remains a challenge and is a promising direction for future work.

3.5 Qualitative Analysis

First, we compare MixQG generated questions to the gold questions annotated in five public QA datasets (Table 4). We find that the generated questions are fluent, relevant, and reasonable to the provided answer and context, even if they differ from the gold label. This further motivates the need of human evaluation for QG research.

Second, we use the HuggingFace summarization pipeline to obtain the summary of the context, and we feed each sentence of the summary as the target answer to MixQG to obtain questions. In this way, we can test MixQG's generalization ability to abstractive answers. As shown in Figure 5, we observe that feeding in long and abstractive answers can still generate fluent and reasonable questions, suggesting that it is possible to control the question's cognitive level by its answer. We leave as future work further research into summary-based unsupervised QA-pair generation.

Lastly, in the Quiz Design study, we find there are 106 cases in which the teachers only accepted a single candidate question into the quiz. MixQG produced the accepted candidate 47 times, more than any of the other models. We provide three examples of such MixQG-only success cases as well as three instances in which the MixQG's question was not accepted in Table 5.

4 Related Work

Question generation's practical importance has lead to an increasing interest in the field. The early work in QG relied on linguistic templates and rules to produce questions from declarative sentences (Heilman and Smith, 2010; Labutov et al., 2015). With the success of neural techniques in text generation tasks, applying neural sequence-to-sequence generation models became more common (Du et al., 2017; Sun et al., 2018). More recent works leverage pre-trained transformer based networks, such as T5 (Raffel et al., 2020), BART (Lewis et al., 2019), PEGASUS (Zhang et al., 2019) and ProphetNet (Yan et al., 2020b), for question generation which have been successful in many applications (Dong et al., 2019b; Lelkes et al., 2021; Rebuffel et al., 2021; Pan et al., 2021).

However, most of the earlier work focuses on using a single QA dataset, such as SQuAD (Rajpurkar et al., 2016). While working on generation of open-ended (Cao and Wang, 2021), controllable (Cao and Wang, 2021), multi-hop (Cho et al., 2021) or cause-effect (Stasaski et al., 2021) questions has gained attention, each direction is studied in isolation as it usually requires a separate QA dataset.

Most directly related to our work is UnifiedQA (Khashabi et al., 2020), which successfully crosses format boundaries of different QA datasets to train a robust QA system. It advocates for more general and broader system designs not limited to specific dataset formats. Similar to their approach, MixQG combines multiple QA datasets and trains a single QG system in a text-to-text paradigm.

5 Conclusion

In this paper, we present MixQG, a question generation model pre-trained on a collection of QA datasets with a mix of answer types. We show through experiments that the resulting model is a strong starting point for further fine-tuning which achieves state-of-the-art results on target datasets in commonly-used similarity metrics as well as our designed human evaluation. We release our code and the model checkpoints to facilitate QG research and downstream applications.

6 Ethical Considerations

MixQG is subject to biases found in the training data of both the underlying text-to-text models and all QA datasets that we have used for pre-training. We do not collect a new dataset for question generation and instead reuse data from previously published works. As such we rely on the published works to follow the responsible data collection practices. The model is currently English language only which limits its practical applications in the real world. We hope to make MixQG multilingual as more diverse QA datasets become available in the future. We validate the proposed model by conducting a human evaluation. We recruited 10 teachers for a study that lasted a maximum of two hours and gifted each participant a $50 gift card.

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A Training Details

Training datasets are listed in Table 3. For training MixQG, we use several pre-trained text-to-text model checkpoints from the HuggingFace library (Wolf et al., 2020). We finetune them for question generation using our combined dataset described in Section 2.1. For most experiments done in this paper, we finetune on a T5-base model (Raffel et al., 2020). We also scale up the model and report results for T5-large, T5-3B, and BART-large settings (Appendix D). We train for 100,000 steps (or 22 epochs) with a learning rate of 3×10^{-5} using the AdamW (Loshchilov and Hutter, 2017) optimizer and a batch size of 32. All training was done on eight A100 NVIDIA GPUs and took approximately 35 hours.

B Quiz Design Task Details

We recruit teachers or ex-teachers from an online group forum. In total, 20 participants filled out the interest form, 14 were selected, and 10 completed the study. The participants had been teachers for at least a year and 3.6 years on average, and had taught diverse subjects such as sciences, history, literature, and IT topics, at various levels from primary school to college-level. The study was meant to last a maximum of two hours, and participants were gifted a $50 gift card upon completion.

Participants were tasked with creating between 5-7 quizzes, each with a minimum of 8 concepts, and could pick from a set list of 7 quiz topics, which we pre-selected from the list of featured Wikipedia articles[3]. We purposefully selected articles within different domains to benchmark the QGen models in diverse topical settings: two in physics (Sustainable Energy, Californium Atom), two in biology (DNA, Enzymes), two in history (Statue of Liberty, Palazzo Pitti), and one in geology (the K-T extinction). Participants were given the first 500 words of the Wikipedia page of each topic as reading material to select Quiz concepts from. User interface is shown in Figure 4. Hierarchical categorization of errors for question generation is shown in Figure 3.

C Qualitative Study Details

To understand MixQG's performance beyond automated metrics, we analyze its generated questions in Table 4. It shows several examples of questions generated by MixQG-3B on the validation sets of different datasates along with the ground-truth questions. We also generate question-answer pairs on Wikipedia articles using a pipeline approach as shown in Figure 5. First, we use a summarization model [4] to obtain the summary of the context. Then we feed each sentence of the summary as the target answer to MixQG and obtain the questions. We observe that the generated questions are grammatically fluent, relevant to the input, and answerable by the target answer paragraph. We find that feeding in longer answers to the model generates more general, higher-level questions about the source article, while short answers prompt more factoid-style questions. As a result, we are able to generate questions of varied cognitive levels from the same source document by restricting the answer part of the input.

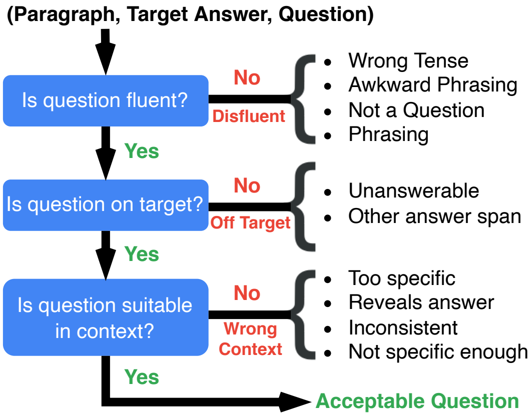


Figure 3: Hierarchical categorization of errors for question generation. Three error categories (Disfluent, Off Target, Wrong Context) each with several subtypes.

D Scaling

Table 6 shows the performance of differently sized MixQG models on SQuAD dataset. We additionally train MixQG model based on BART-large checkpoint, referred to as MixQG$^{BART}_{large}$. As expected, the largest MixQG model (3 billion parameters) performs best among the different model size variants.

[3] https://en.wikipedia.org/wiki/Wikipedia:Featured_articles

[4] https://huggingface.co/facebook/bart-large-cnn

Dataset	**Type**	**Source**	**Train examples**	**Dev. examples**
SQuAD (Rajpurkar et al., 2016)	Extractive	Wikipedia	86,588	10,507
NewsQA (Trischler et al., 2017)	Extractive	News	74,160	4,212
TriviaQA (Joshi et al., 2017)	Extractive	Web	61,688	7,785
SearchQA (Dunn et al., 2017)	Extractive	Web	117,384	16,980
HotpotQA (Yang et al., 2018)	Extractive	Wikipedia	72,928	5,904
NQ (Kwiatkowski et al., 2019)	Extractive	Wikipedia	104,071	12,836
NarQA (Kočiský et al., 2018)	Abstractive	Wikipedia, Project Gutenberg	32,747	3,461
MCTest (Richardson et al., 2013)	Multiple-Choice	Stories	1,200	600
BoolQ (Clark et al., 2019)	Yes-No	Wikipedia	9,427	3,270
Quoref* (Dasigi et al., 2019)	Extractive	Wikipedia	19,399	2,418
DROP* (Dua et al., 2019)	Abstractive	Wikipedia	77,400	9,535
QAConv* (Wu et al., 2021)	Extractive	Email, Panel, Channel	25,988	3,251

Table 3: Dataset Statistics of various QA corpora. * indicates unseen corpus during training.

Dataset	Source	Questions
SQuAD	Gold	What happened to NASA's yearly budget after the first landing?
	MixQG	What happened to NASA's budget after the first successful moon landing?
	Gold	How many of Warsaw's inhabitants spoke Polish in 1933?
	MixQG	In 1933, how many of Warsaw's inhabitants were of Polish mother tongue?
	Gold	How long does it take for new areas to have significant oil production?
	MixQG	How long did it take to develop new oil fields?
NarQA	Gold	What are Mulder and Scully doing at the beginning of the story?
	MixQG	What are Mulder and Scully doing in Dallas?
	Gold	How does Chris make extra money?
	MixQG	What does Chris Hughes do for a living?
	Gold	Who died in this story?
	MixQG	What is the name of Mortimer Tregennis's sister?
MCTest	Gold	How many of Mikes friends came to the party
	MixQG	How many of Mike's friends came to the party?
	Gold	Where did Jenny want to go on a trip to?
	MixQG	Where did Jenny want to go on a trip?
	Gold	What was Stewart doing at the beach?
	MixQG	What was Stewart doing when he saw the bug?
BoolQ	Gold	is there an amtrak station in pensacola florida
	MixQG	is there an amtrak station in pensacola florida
	Gold	can a minor sit at a bar in nj
	MixQG	can a minor drink at a bar in new jersey
	Gold	can a polar bear and a grizzly mate
	MixQG	is there such a thing as a grizzly polar bear
QAConv	Gold	What Xbox 360 game is the best dance game for a wife on the Wii?
	MixQG	What is a good dance game for the Wii?
	Gold	Which state is taking its proper place and represents the country's diversity much better?
	MixQG	What state is taking its proper place as early in the primary?
	Gold	In what month will the BLM say go ahead and start the stimulation experiment ?
	MixQG	When will the experiment start?

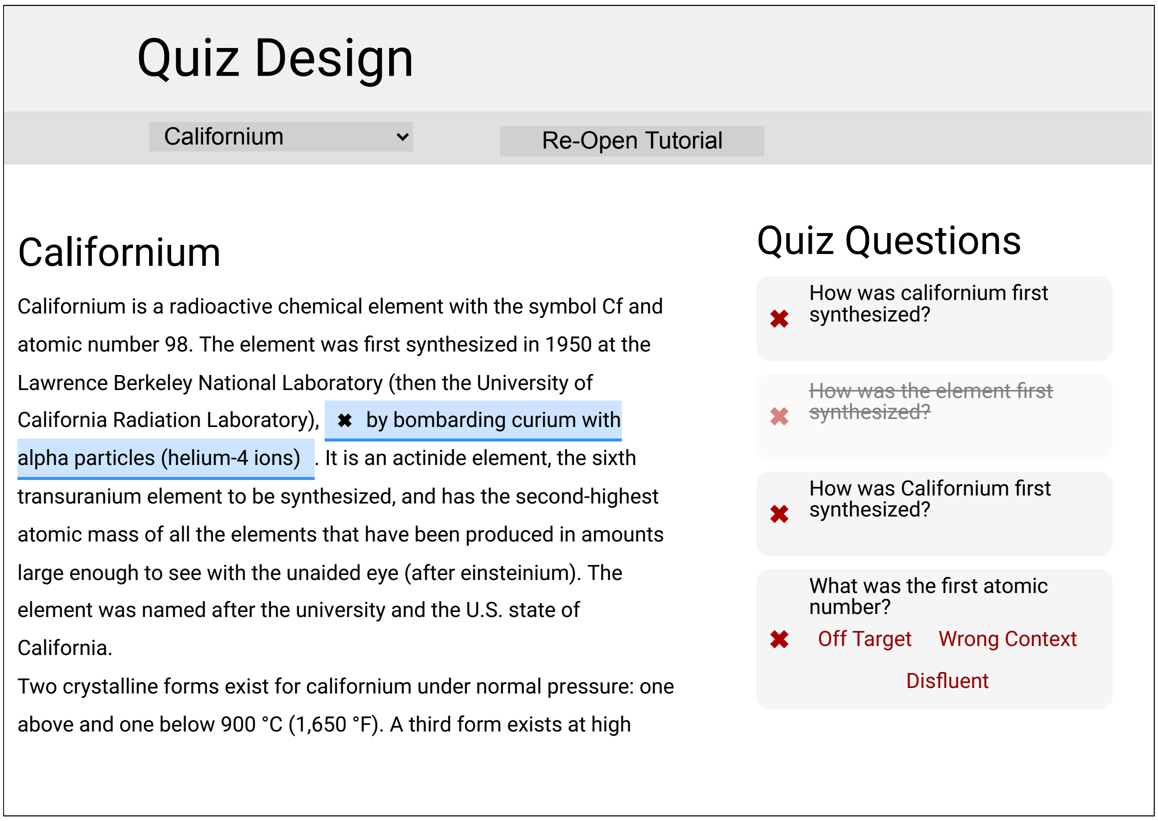
Table 4: Example of MixQG-3B generated questions and their corresponding ground-truth labels.

Context	**Model**	**Question**	**Annotation**
For example, californium can be used [...] when studying materials using **neutron diffraction and neutron spectroscopy**.	MixQG-L	What methods are used to study materials using californium as a source of neutrons?	No Error
	BART-L	What is Californium used to study materials?	Disfluent
With the exception of some ectothermic species [...] no tetrapods **weighing more than 25 kilograms** (55 pounds) survived.	MixQG-L	What size tetrapods did not survive the extinction?	No Error
	ProphetNet	How much did tetrapods weigh at the time of the Cretaceous-Paleogene extinction?	Off Tgt.
The two DNA strands are known as polynucleotides as they are composed of **simpler monomeric units called nucleotides**.	MixQG-L	What are polynucleotides composed of?	No Error
	BART-L	What are polynucleotides?	Off Tgt.
The Statue of Liberty (**Liberty Enlightening the World**) is a colossal neoclassical sculpture on [...]	ProphetNet	What is another name for the Statue of Liberty?	No Error
	MixQG-L	What is the English translation of the Statue of Liberty?	Off Tgt.
Californium. The element was named **after the university and the U.S. state of California**.	ProphetNet	What is Californium named after?	No Error
	MixQG-L	Where did Californium get its name?	Wrong Ctxt
Fossil fuels provide 85% of the world's energy consumption and the energy system [...]	BART-L	How much of the world's energy consumption does fossil fuels provide?	No Error
	MixQG-L	What percentage of the world's energy consumption is fossil fuels?	Disfluent

Table 5: **Success and failure cases of the MixQG model from the Quiz Design evaluation.** Comparisons to the ProphetNet and BART-Large models are included, with each model receiving the context with a target answer (in bold), and being annotated with an error label by a teacher.

Model	BLEU	R1	R2	RL	RLsum	METEOR	BERTScore
ProphetNet$_{large}$	22.88	51.37	29.48	47.11	47.09	41.46	0.4931
MixQG$^{BART}_{large}$	23.30	54.44	31.92	50.18	50.18	43.47	0.5622
MixQG$_{base}$	23.53	54.39	32.06	50.05	50.02	43.83	0.5566
MixQG$_{large}$	24.42	55.52	33.13	50.99	50.97	45.07	0.5699
MixQG$_{3b}$	**25.42**	**56.11**	**33.91**	**51.85**	**51.86**	**45.75**	**0.5789**

Table 6: Evaluation of differently-sized MixQG models on SQuAD. Base, Large and 3B refer to model configurations with 220 million, 770 million and 3 billion parameters, respectively.



Quiz Design

Californium

Californium is a radioactive chemical element with the symbol Cf and atomic number 98. The element was first synthesized in 1950 at the Lawrence Berkeley National Laboratory (then the University of California Radiation Laboratory), ✖ by bombarding curium with alpha particles (helium-4 ions) . It is an actinide element, the sixth transuranium element to be synthesized, and has the second-highest atomic mass of all the elements that have been produced in amounts large enough to see with the unaided eye (after einsteinium). The element was named after the university and the U.S. state of California.

Two crystalline forms exist for californium under normal pressure: one above and one below 900 °C (1,650 °F). A third form exists at high

Quiz Questions

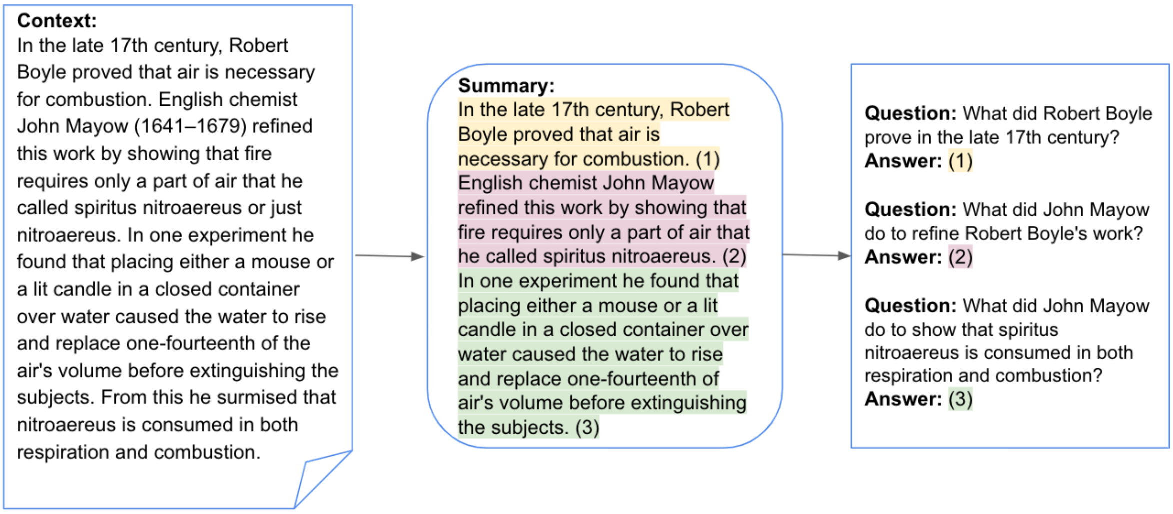
✖ How was californium first synthesized?

✖ ~~How was the element first synthesized?~~

✖ How was Californium first synthesized?

✖ What was the first atomic number?

Figure 4: **Screenshot of annotation interface used for the Quiz Design Task.** The teacher has selected the concept highlighted in blue in the reading material in the left column. In the right column, the system gives proposes candidate questions, which can be added to the quiz, or refused with a reason.



Context:
In the late 17th century, Robert Boyle proved that air is necessary for combustion. English chemist John Mayow (1641–1679) refined this work by showing that fire requires only a part of air that he called spiritus nitroaereus or just nitroaereus. In one experiment he found that placing either a mouse or a lit candle in a closed container over water caused the water to rise and replace one-fourteenth of the air's volume before extinguishing the subjects. From this he surmised that nitroaereus is consumed in both respiration and combustion.

Summary:
In the late 17th century, Robert Boyle proved that air is necessary for combustion. (1) English chemist John Mayow refined this work by showing that fire requires only a part of air that he called spiritus nitroaereus. (2) In one experiment he found that placing either a mouse or a lit candle in a closed container over water caused the water to rise and replace one-fourteenth of air's volume before extinguishing the subjects. (3)

Question: What did Robert Boyle prove in the late 17th century?
Answer: (1)

Question: What did John Mayow do to refine Robert Boyle's work?
Answer: (2)

Question: What did John Mayow do to show that spiritus nitroaereus is consumed in both respiration and combustion?
Answer: (3)

Figure 5: Example of generating QA pairs using summarization and MixQG.