Generative Large Language Models for Dialog-Based Tutoring: An Early Consideration of Opportunities and Concerns

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Abstract

After many years of relatively limited capabilities for generative language models, recent large language models (LLM's) have demonstrated qualitatively better capabilities for understanding, synthesis, and inference on text. Due to the prominence of ChatGPT's chat system, both the media and many educational developers have suggested using generative AI to directly tutor students. However, despite surface-level similarity between ChatGPT interactions and tutoring dialogs, generative AI has other strengths which may be substantially more relevant for intelligent tutoring (e.g., detecting misconceptions, improved language translation, content generation) and weaknesses that make it problematic for on-the-fly tutoring (e.g., hallucinations, lack of pedagogical training data). In this paper, we discuss how we are approaching generative LLM's for tutoring dialogs, for problems such as multi-concept short answer grading and semi-supervised interactive content generation. This work shows interesting opportunities for prompt engineering approaches for short-answer classification, despite sometimes quirky behavior. The time savings for high-quality content generation for tutoring is not yet clear and further research is needed. The paper concludes with a consideration of longer-term equity and access in a world where essential capabilities require low-latency real-time connections to large, pay-peruse models. Risks and mitigating technologies for this kind of "AI digital divide" are discussed, including optimized / edge-computing LLM's and using generative AI models as simulated students to train specialized tutoring models.

Keywords

Intelligent Tutoring Systems, Conversational Tutoring, Generative Models, Large Language Models, Short Answer Grading, Content Generation

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1. Introduction

A student studies how DNA works by asking for information from a chat system, which answers all their questions about the parts of genes they find unclear. Is this a tutoring system? Since the rise of ChatGPT [12], the lines between a classical information system (e.g., Google Search) and a dialog-based assistant have blurred. To some extent, this process has been ongoing for many years: Google Search results generate question-answer pairs and text summaries; Amazon Alexa tries to paraphrase Wikipedia facts; etc. However, ChatGPT is notable because it pioneers the combination of two capabilities: highly-effective text instruction (prompting) and meaningful multi-turn context. On the surface, using ChatGPT to study a topic can look somewhat similar to a tutoring dialog: the highly-knowledgeable "tutor" answers all the questions to help the learner and (sometimes) can suggest places to read more if it doesn't have all the answers.

However, research on human tutors shows this is mostly not how effective tutoring works. The described interaction more closely resembles a reference librarian or an inhumanly fast legal researcher. It is fairly straightforward to establish that ChatGPT and any relatively easy extension is not a tutor. Expert tutors typically differ in three major ways:

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1. Initiative: The tutor guides the conversation stages and direction. Even when answering questions or listening to extensive student explanations, they are managing the interaction rather than reacting to it.
2. Answering vs. Questioning: When tutors interact with a student, they are often posing questions (e.g., prompting the student to think) rather than just responding to questions. Even when providing explanations, the tutor typically uses these to set up their next tutoring moves.
3. Pedagogical Domain Knowledge vs. Domain Knowledge: Tutors and instructors are uniquely experienced with a wide range of student understandings and misconceptions, as well as which strategies seem to work better with different students. Current LLM data sets lack many examples of pedagogical domain knowledge.

Despite this, the utility of the "Instruct GPT" technology behind ChatGPT remains compelling and can at a minimum produce simple interactions that are known to be helpful. For example, research shows that self-testing [18] or self reflection dialogs [21] improve learning versus merely reading passive materials like a textbook. This raises significant questions. What roles can generative AI play between a free-form dialog and a close-ended knowledge check? Why might a more flexible dialog agent be a worse tutor? When could generative AI be ready to tutor and what would the implications be?

In this work, we present our current perspective on these issues from the standpoint of exploring these emerging models. Due to the rapid convergence of generative AI capabilities, the views and assumptions in this paper will be inherently more speculative than the typical paper. As such, the goal is to contribute to the present-day discussion and to offer a reference point to re-evaluate 2-3 years in the future, when research studies have established empirical evidence on the areas where generative AI models have successfully improved versus failed to advance learning outcomes.

2. Background: Generative LLM's for Education

Compared to many AI topics, the history of generative language models for intelligent tutoring systems is relatively thin. Excluding template-based systems (e.g., generating math problems by customizing fields), little research was conducted on this topic until the last few years. In part, this has been due to the poor quality of generated text. Early successes were not very useful for most learning contexts, such as simple summaries, paraphrases, or structured narratives (e.g., baseball play-by-play). Moreover, even research as recent as this year reported that GPT-3 produced math explanations that teachers rejected about 50% of the time [16]. Similarly, research with ChatGPT indicates that it produced better-written hints (70% acceptable by experts) but that these accepted hints may have still produced lower learning gains than human-generated hints [14]. Anecdotally, at least for math, GPT-4 [13] may produce significantly better explanations than GPT-3, but as reported in [14], such content may still be less effective than teachers would make themselves.

In short, even as recently as early 2023, the quality of raw content generated by an LLM has not shown that it should be used with students if human-created content is available instead. While the quality of generated content is rising rapidly year after year (e.g., one current but informal estimate is 80% acceptance), a rejection rate of even 5% would make teachers wary of students using the content as-is. The nature of errors is also problematic, with well-documented issues of hallucination (e.g., making up fictional facts) and over-confident explanations [6]. While emerging practices in prompt engineering and improved models offer ways to reduce these issues, they are to some extent inherent and may not be resolved reliably in the next few years. As a predictive model generates a stream of coherent and mostly self-consistent text, one turn down the wrong path can lead to an extremely coherent rationale for why the wrong answer is right. From a learning standpoint, this is among the worst failures: a compelling, well-reasoned misconception.

A final issue for LLM tutoring is that there is no cut-and-dry evidence that supporting exploration and open-ended question answering provides greater learning efficiency. Conversely, research efforts have found that in some cases less exploration is appropriate: vicarious tutoring (watching a teacher agent work with a student agent) can be particularly effective for low-knowledge learners [3], expert tutors in some cases provide more prescriptive "collaborative lectures" than less-experienced tutors [11], and worked examples have been almost 50% more efficient than problem-solving for certain types of learning [8]. This is compounded by the fact that interacting productively with a relatively unconstrained dialog-based tutor has distinct issues. First, students with weak self-regulated learning (SRL) skills may struggle to ask productive questions and require training on SRL to engage effectively (e.g., metacognitive scaffolding [2]). While this may be a strength in the long term, approaching both problems simultaneously poses a challenge. Second, students may become distracted with content that neither aligns with their course nor their long-term goals (e.g., similar to reading through a series of Wikipedia links despite finding the desired information). Ultimately, open-ended conversations may prove most effective for students with strong SRL skills, who often already learn faster.

Despite these concerns for generative models chatting in real-time educational conversations, the case for semi-supervised content remains strong. First, there is no requirement that LLM-generated explanations or hints must be used as is. Instructors and content developers regularly improve or adapt mixed-quality content. Second, significant infrastructure is growing to enable comparison of different types of learning content, either across versions of a course template (e.g., the WISE project; [22]), through randomized micro-trials of certain content [24], or through frameworks designed to deploy large-scale A/B testing of interventions [17]. Tools to more rapidly produce, review, and revise content can have powerful synergies with frameworks designed to evaluate the effects of these changes. In the long term, such results can also be used in a feedback loop where generative models can be tuned and prompted to produce higher-quality educational materials.

3. Current Directions: Generative LLM's for Tutoring

In ongoing work, we have started exploring prompt-based LLM approaches to support dialog-based intelligent tutoring. We are targeting two problems where LLM's have already shown advantages: automated short answer grading (ASAG) [7,23] and content generation suitable for expert review [14].

This work is done in the context of OpenTutor (www.github.com/opentutor/ [10]), a rapidly-authorable dialog-based tutoring system designed to allow instructors and other non-specialized authors to create and share tutoring dialog lessons. OpenTutor follows expectation-based tutoring approaches based on AutoTutor, which has demonstrated learning gains on a variety of domains [5,9]. While instructors using OpenTutor have reported that it has high usability and instructors can create a dialog fairly easily, tuning the grading of answers remains a key technical challenge: the classifier starts with only a single ideal answer statement for each expectation concept. Typically, about 20-25 students must complete tutoring sessions and instructors grade student answers to provide sufficient training data for good-quality evaluation of new student answers (e.g., 85% accurate or higher on each expectation concept).

Cold start performance with the fewest number of examples (0-shot and N-shot classification) is important to save instructor grading time and avoid potential student frustration for the first batch of learners. For current OpenTutor dialogs, the classifier typically starts at 65% to 80% accuracy without any labeled student answers. This is a multi-label classification task, as every student answer is graded on each concept as either true (student showed they knew the concept) or false (student did not show that they knew the concept). The confidence of the classifier must also be reported, as the OpenTutor dialog model responds differently to low-confidence classifications (e.g., neutral feedback and responses). Since it is infeasible to fine tune a language model for each new les son, prompt-based N-shot approaches offer a way to improve the classifier when little or no data is available.

LLM prompts will also be explored as a tool to take an input document (e.g., cliff notes, video transcript) and learning objective(s), and generate an OpenTutor lesson candidate. This task is substantially more complex than previously studied content generation, because it requires generating a question prompt, expectation ideal answers, and for each expectation an average of two hints framed as leading-questions (e.g., "If you changed the polarity, what would happen?"). Moreover, the order of the expectations and the hints are pedagogically meaningful (e.g., hints should progress from more general to more specific). The first step is prompt engineering to determine the feasibility of generating each element. While existing research indicates that it should be possible to generate an OpenTutor lesson candidate, significant evaluation would need to be conducted to quantify the added-value of these dialogs. The lesson candidates must save significant time (i.e., selecting and revising a lesson must be easier than making one manually), and the dialogs must produce equivalent or better engagement and learning gains.

4. Prompt Engineering for Short-Answer Grading

Our exploratory research is investigating the feasibility of using LLM's to improve short-answer grading when limited data is available through design of a prompt which can be used to classify a student input for its coverage of multiple concepts simultaneously. The inputs to this prompt are a list of ideal answer expectations (labeled "concept_1" to "concept_N"), a JSON structure for N-shot labeled examples, and one or more student answers to classify. The output is a JSON structure containing the label for each concept (true/false), the confidence for that label, and a text justification for the label. In this initial work, ChatGPT is being used, though since only a single prompt is provided (no chaining) it should be effectively equivalent to a single InstructGPT prompt.

An example prompt is presented in Appendix A. Due to rapid iteration on the prompts at this time, it is only one of a number of candidate templates being explored. The design of these prompts was based on surveying a large variety of examples and approaches (e.g., pre-publications, Reddit communities, and blog posts; e.g., [4]), with the most influential being efforts to minimize hallucinations while retaining effective inference. We also asked the model itself what approaches should be most effective for issues such as providing data. From this guidance, we identified a number of the key prompt engineering elements that are required for a short answer grading task:

1. Instructions: Short narrative directions and context clarifications, which are minimally-sufficient to get consistent and meaningful results.
2. Structured Data: Highly structured (e.g. JSON, CSV) inputs and outputs. Example data (ground truth) should be in the same format as the desired output.
3. Justification: Requesting that the model justify the reason for its label, rather than only generating the label.
4. Emphasizing Key Elements: Insisting, repeating, or asking to double-check key instructions to give them greater weight (e.g., that the output must be valid JSON).

As shown in Appendix A, there is an initial system instruction (system assignment), which contextualizes the task–in this case that of a tutor evaluating answers (user-concepts)–and then presents unlabeled data in JSON format (user-answers). The user prompt next indicates the steps of evaluation and response (user-template), which includes a brief justification and a confidence score included in a JSON formatted template for a response. In the N-shot examples, there is then a brief narrative that provides "ground truth" examples followed by labeled data in JSON format (user-ground truth). Ground truth was the terminology used by ChatGPT when responding to a question about preferred formats. Finally, there is a coda statement that asks for confirmation that all responses are properly formatted (user-guardrails). In this statement, we also use a special term for setting the "temperature" of the model. This is associated with the level of variation in generation: a temperature of 0 will produce the same result each time, while higher values are typically used for creative tasks (e.g., fiction writing prompts). Using this formula the response is consistent and in most cases quite effective, with baseline responses often yielding an accuracy of above 80% on certain initial examples tested.

Figure 1 shows exploratory results of ChatGPT as a short-answer multiconcept classifier for answers for a dialog on reaching out for mental health services (Reaching Out) and Figure 2 shows similar results for a dialog related to suicide prevention (Prevention). Each example shows a single run where the same test set of 20 answers is used while the number of labeled examples (N-shots) is increased from 0 to 15. Despite this, fairly clear trends show improvement of the F1 scores for both dialogs as more examples are provided. However, examining specific expectations shows that in many cases one or two expectations are classified fairly well even at baseline, while other concepts require substantially more examples. Considering classifications of the two dialogs, it is also interesting that the one appears to be pickier than the other (e.g., one consistently shows higher precision while the other shows higher recall). From an authoring standpoint, tuning the classifier to be more selective versus more permissive in accepting answers would ideally be possible through prompt engineering, but has not proven reliable so far.

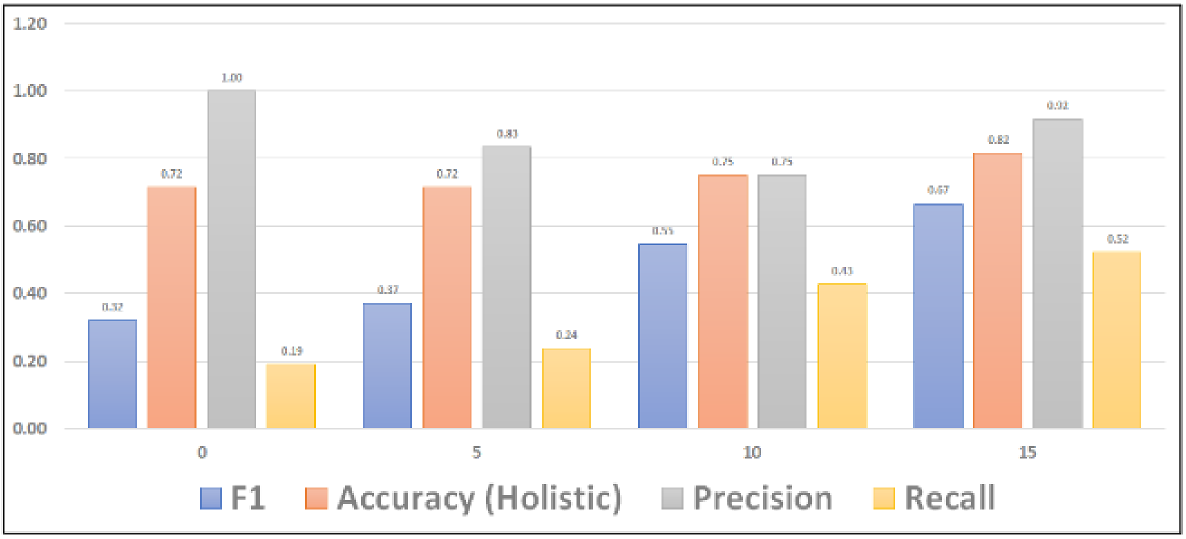


Figure 1: “Reaching Out” Classifier Performance by N-Shots Labeled

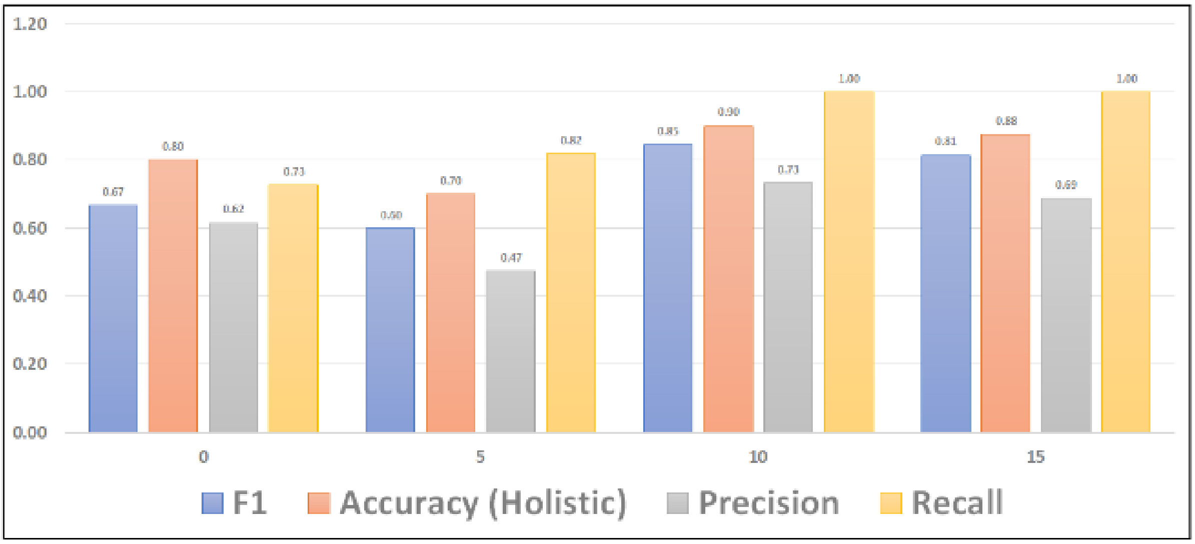
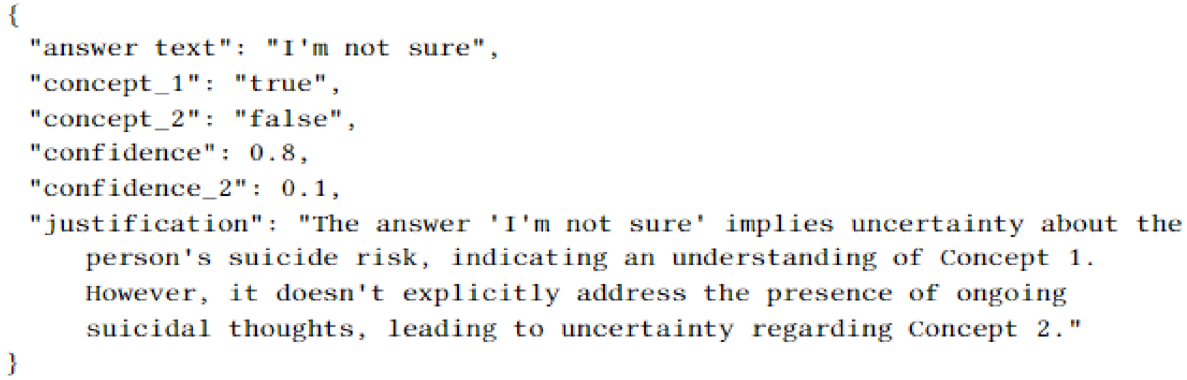


Figure 2: “Prevention” Classifier Performance by N-Shots Labeled

As a result, external verification of inputs versus outputs is an obvious need. While in some cases labeled examples help induce highly insightful justifications (e.g., correctly identifying metaphors or word-play), in other cases the output format is not produced correctly, labeled data is ignored, or an answer classification is missing when multiple were requested. Moreover, in one case it actually generated an additional answer that was classified (see Fig. 3 below). Small changes in the prompt can also cause large-scale consequences. For example, when tests included the tutor's main question, this appeared to cause the grading to be much harsher and hurt the accuracy significantly as a result. As a third intuition, once the LLM answers in the wrong direction for a prompt, it appears to cause additional cascading errors (e.g., it added "I'm not sure" as an answer and also said that was a correct match for an expectation, which it was most certainly not).



```
{
  "answer text": "I'm not sure",
  "concept_1": "true",
  "concept_2": "false",
  "confidence": 0.8,
  "confidence_2": 0.1,
  "justification": "The answer 'I'm not sure' implies uncertainty about the
      person's suicide risk, indicating an understanding of Concept 1.
      However, it doesn't explicitly address the presence of ongoing
      suicidal thoughts, leading to uncertainty regarding Concept 2."
}
```

Figure 3: Hallucination Example: Classifying a fictional student answer

Exploration to date implies the need to combine LLM classifiers with supporting models. First, a validator or critic model must check LLM answers, as catching a single problem may require re-generating the whole response. Second, tools are needed to adjust ROC curve behavior by an LLM. In exploration with the ChatGPT model, the generated "confidence" produces 0-1 scores easily but may ignore instructions to use a -1 to 1 range. Moreover, confidence ratings are connected to the "temperature" parameter: reducing the temperature to zero results in a confidence of 1 for every label. As such, using the LLM deterministically breaks the confidence scores. Even where confidence scores are available, they often appear over-confident and imprecise (e.g., tend toward even-numbers like 0.6 and 0.8). Research is needed to optimize for different metrics for a task (e.g., recall vs. precision) and techniques to combine LLM with reliable models (e.g., ones where confidence is more predictive with correct labels). Alternatively, fine-tuned LLM's may be possible which optimize for tuning parameters.

While this work is at an early stage, one key finding is the necessity to wrap generative models with external systems for standardization and evaluation rather than using their raw results to interact with learners. This is likely relevant at multiple levels, beyond the basic elimination of hallucinations or detecting a missing classification. While minor tweaks to submissions can have significant impacts (in one case changing a single classification label was enough to yield a drop in recall score by over .3), this remains an outlier. In general, when properly structured, classification responses yield F1 scores ranging .6 to .9, where greater numbers of labeled data in the prompt improves the F1 score. The generated justifications also represent interesting candidates for tutoring dialog statements, but due to the cascading error problem these would only be trustworthy if a secondary higher-reliability classifier agrees with the label. Further areas of investigation include: the impact of multi-stage versus single stage prompting, methods for validating confidence scores, the impact of asking for various numbers of classifications simultaneously (e.g. 2 concepts vs. 5 concepts), and optimal batch sizes (e.g., how many student answers can be graded with a single "setup prompt" without introducing noise).

5. Conclusions

The exploration conducted so far indicates that prompt engineering can be an effective method for short answer grading with ChatGPT which is expected to complement the existing lightweight classifier from OpenTutor. More generally, this research also integrates some specific techniques that improve classification using InstructGPT prompts (e.g., requiring a justification, structured example data, clear and emphatic context). Despite intermittent failures due to hallucination or other issues, this research indicates that it is feasible to plug a LLM into a real-time tutoring system for answer evaluation by wrapping it in services to generate the prompt and validate the answer format. Upcoming research will investigate the benefits of ensembling the LLM with the existing OpenTutor classifier, which remains an important fallback model and a model that can be used offline without an internet connection.

Research on generating interactive learning content with LLM is still exploratory. However, compared to raw LLM chat dialogs, we believe that semisupervised content generation is more appropriate for the current state of the art. This should not be considered a negative: the ability to rapidly generate related versions of content should make it possible to systematically compare different types of content for different kinds of learners and situations (e.g., self-reflection prompt vs. multiple choice quiz vs. collaborative lecture vs. expectation-based tutoring, etc.). Moreover, for intelligent tutoring systems and other interactive learning content, generative tools which speed up producing or updating content will be highly significant. Despite established research that active, interactive, and constructive learning activities produce greater learning [1], many courses spend over 80% of class time on passive content (e.g., lectures, text, video) [19]. Enabling faster generation and grading of interactive learning content could help make interactive content more prevalent.

In the cases where no vetted active learning content exists yet (e.g., emerging topics), a directly generated learning dialog comparable to ChatGPT about the content should still provide value much like how self-testing improves learning. However, such fully-generated content is unlikely to match instructor-authored content, because teachers also leverage domain-specific understanding of student learning and techniques to use complementary media effectively (e.g., diagrams, videos, worked examples). Even after including these factors, traditional educational topics would likely benefit most from systematically optimizing their language within a more constrained dialog rather than generating all responses on-the-fly.

5.1. Broader Considerations

As hosted and proprietary LLM's become important for emerging learning technologies, this also raises the risk of a new digital AI-divide. Due to their memory footprint and computational requirements, current LLM models charge a non-trivial fee per use and, perhaps more problematic, require real-time responses from a reliable internet connection. Even as internet access grows worldwide, technology and business models for AI using large foundation models (LLM's, AI vision, etc.) may remain less accessible to low-resource learners. Policies and standards to ensure that equitable use of these technologies are also important, particularly for versions designed to meet the needs of developing regions (e.g., inconsistent internet, mobile-first computing devices).

For example, efforts are underway to build "distilled" models based on LLM, such as a specialized short-answer grading model based on ChatGPT [7]. However, due to the current licensing constraints, many of these models remain incompatible with distribution. Alternatively, LLM might be used to develop the behavior of better simulated students who test out content or policies from smaller specialized models. In this role, the LLM would be part or all of a cognitive model designed to produce better training data for other models. Exploration of these approaches has already started in domains such as teaching programming skills [15] and biology [20]. Smartphone platforms (e.g., iOS, Android) can play an important role for increasing equity by expanding mechanisms to download shared AI/ML libraries accessible across apps. By establishing approaches to ensure equitable access now, these models can be replicated as increasingly advanced and useful models set a new baseline for what we can accomplish with educational technologies.

5.2. Future Directions

Based on these trends, our current research focuses on two directions. First, the presented work will integrate into an ensemble short answer classifier that combines a hosted LLM and a fast self-managed classifier. The fast classifier will be designed offset LLM limitations in response availability (where the LLM is too slow or costly for a real-time chat response) and confidence signals (attempt to avoid over-confidence and select neutral feedback when appropriate). Research is also necessary to pick N-shot examples for the LLM effectively out of a larger set. The metrics for success in this endeavor will be improved classification (e.g., f-score) with fewer than 20 examples. During experiments with the classifier, we will also store the LLM's justifications to consider if or when these might be useful suggestions for hints or feedback by the tutor.

Our longer-term direction to also co-generate content for a tutoring dialog from a passive content module (e.g., 1-3 page overview, brief video). This will require iterative prompts and may require (or at least benefit from) initial information, such as the author's key learning objectives. We conceive this as three distinct challenges: identifying key concepts, generating a main question where students must explain with a coherent set of those concepts, and generating a progression of hints. This is a substantial challenge, as current LLM's struggle to reliably generate single hints, but fine-tuning and/or careful chaining approaches may still help save time for first-draft content. Ideally, a tuned model might also generate candidate content aligned to a specific pedagogical approach (e.g., decomposing the problem vs. learning by teaching). This would enable less-experienced authors to build more advanced tutoring content. To this end, we may leverage existing ITS dialog sessions as training data for an LLM, as these also include structured data and metadata. These advanced features will explored incrementally, as co-generated ITS content should use ongoing testing to ensure comparable learning gains for the same concepts as a baseline ITS.

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Appendix A InstructGPT / ChatGPT Prompt Template

system-assignment:The user provided a list of one or more "answers" to a tutoring question. The answers are provided in JSON format. You are a tutor who is evaluating if the answer is sufficient to show that the user knows a one or more "concepts" which will be labeled "concept_1" to "concept_N". For each answer you evaluate, you must also express how confident you are in your evaluation of how well the answer shows knowledge of each concept. You will also provide a brief justification.

user-concepts:These are the concepts for this lesson.
Concept 1: Normal diodes do not conduct current in reverse bias and act like an "off" switch.
Concept 2: The diode will be damaged by going into breakdown mode.

user-answers:These are my answers provided in JSON to be evaluated.

```
{
 "answer_28": {
  "Answer text": "it will burn out"
 },
 "answer_50": {
  "Answer text": "The diode is off."
 }
}
```

user-template:Respond with a JSON in the following format for each concept.

```
{"answer number": // state the numerical label associated with the answer.
 "answer text": string // state the text of the particular answer being classified.
 "concepts" : {
   "concept_N" : {
              "is_known": string // true or false. If the input answer implies that the concept is known, the classification should be true. Otherwise it should be false.
              "confidence": float // A 0 to 1 score indicating certainty that a classification is correct. Confidence scores closer to 1 represent higher certainty, and confidence scores closer to 0 represent lower certainty.
               "justification": string // Why you believe the user answer is or is not sufficient to determine if they know the concepts.
              }
  }
}
```

user-groundtruth:Here are some examples that have already been labeled. They are presented in JSON format, where the answer is given, followed by each concept and a true or false label. Consider these to be ground truth examples.

```
{
 "answer_34": {
  "Answer text": "It redirects the current.",
  "concept_1": "true",
  "concept_2": "false"
 },
 "answer_10": {
  "Answer text": "it burn out",
  "concept_1": "false",
  "concept_2": "true"
 },
 "answer_21": {
  "Answer text": "Will not allow current to flow.",
  "concept_1": "true",
  "concept_2": "false"
 },
 "answer_32": {
  "Answer text": "turns off",
  "concept_1": "true",
  "concept_2": "false"
 },
 "answer_24": {
  "Answer text": "the voltage changes direction",
  "concept_1": "true",
  "concept_2": "false"
 }
}
```

user-guardrails:Only respond with the JSON output and no other words or symbols. The output must be valid JSON. Check that the output is valid JSON. Return responses with a temperature of 0.3

Appendix B InstructGPT / ChatGPT Prompt Template

role:assistant

```
content:{
 "answer_28": {
  "Answer text": "it will burn out",
  "concepts": {
   "concept_1": {
    "is_known": false,
    "confidence": 0.8,
    "justification": "The answer implies that the diode will burn out, but does not mention anything about current flow or the diode acting like an 'off' switch."
   },
   "concept_2": {
    "is_known": true,
    "confidence": 0.9,
    "justification": "The answer correctly states that the diode will burn out, which can happen when it goes into breakdown mode."
   }
  }
 },
 "answer_50": {
  "Answer text": "The diode is off.",
  "concepts": {
   "concept_1": {
    "is_known": true,
    "confidence": 0.9,
    "justification": "The answer correctly states that the diode is off, which means it is not conducting current in reverse bias and acting like an 'off' switch."
   }
```