CodeEvo: Interaction-Driven Synthesis of Code-centric Data through Hybrid and Iterative Feedback

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Abstract

Acquiring high-quality instruction-code pairs is essential for training Large Language Models for code generation. Manually curated data is expensive and limited in scale, motivating the development of code-centric synthesis methods. Yet, current approaches often rely on predefined heuristics, resulting in synthetic data that is ungrounded, repetitive, or simplistic. We propose *CodeEvo*, a framework inspired by collaborative programming that employs two interacting LLM agents. A Coder generates and refines solutions, while a Reviewer directs the synthesis process. To overcome the limitations of simple heuristics, the Reviewer first constructs a Schema, a structured blueprint that explicitly plans the logic, constraints, and complexity of a new instruction prior to its generation. This planning process is complemented by a hybrid feedback mechanism that combines compiler determinism with the agent's semantic evaluation, ensuring rigorous quality control. Extensive experiments demonstrate that models fine-tuned on *CodeEvo* data significantly outperform established baselines across code generation benchmarks. In-depth analyses further provide insights into effective code-centric data synthesis.

1 Introduction

The rapid development of Large Language Models (LLMs) has significantly advanced code intelligence [1], powering applications ranging from line-level code completion to competition-level problem solving. To further enhance their performance on code generation, it is essential to train these models with complex, diverse, and grounded instruction-code pairs [2]. While manually curated data serve as ideal resources, their collection is labor-intensive, difficult to scale, and gradually exhausted [3]. These limitations have stimulated growing interest in constructing code-centric synthetic data with minimal human intervention. After early attempts that leverage symbolic augmentation over existing code references [4, 5], recent research has shifted toward using LLMs

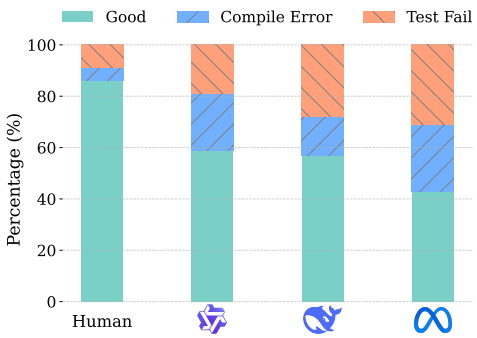

Figure 1: Comparison of synthesized code data quality across human examples and code produced by Qwen2.5-Coder-32B, DeepSeek-V3, and Llama-3.1-8B.

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to automatically generate instruction-code pairs. These methods, such as Evol-Instruct [6], aim to bootstrap data using powerful models and predefined heuristics. While these approaches enable data construction, they often fall short in ensuring semantic correctness and executability [7].

As shown in Figure 1, we sample instruction-code pairs synthesized by various (Code)LLMs using Evol-Instruct heuristics [8]. Many of these samples fail to execute or do not pass the provided unit tests, indicating substantial quality gaps. These shortcomings can be attributed to two main factors: (1) instructions are often poorly grounded, leading to vague or inconsistent objectives; and (2) generated codes lack proper validation, due to the absence of robust mechanisms to enforce correctness during synthesis. This motivates a key question: *Can we design a fully automated and reference-free synthesis pipeline that produces well-grounded and executable instruction-code pairs?*

Recently emerging LLM agents have demonstrated strong interactive capabilities [9], enabling them to perform tasks through multi-turn interactions and feedback-driven decision making (*e.g.*, collaborative programming; 10, 11). These make them promising candidates for moving beyond vanilla data generation toward verifiable and adaptive synthesis pipelines. Inspired by this potential, we propose *CodeEvo*, an interaction-driven synthesis framework that orchestrates LLM agents to generate high-quality code-centric data. Specifically, a *Coder* agent produces candidate code and tests based on given instructions, while a *Reviewer* agent provides tailored feedback and dynamically constructs new instructions iteratively.

To address the two core challenges in instruction-code synthesis, *CodeEvo* incorporates two key mechanisms: (1) To lift instruction quality, we introduce a schema-driven synthesis process. Guided by task-specific keywords, a Reviewer agent first constructs a Schema, a structured and adaptable blueprint that plans a new problem's logic and complexity before generating instructions. This transforms instruction evolution from a heuristic-based task into a principled design process. (2) To boost functional correctness, we introduce a hybrid feedback loop that iteratively refines solutions by fusing the deterministic verification of a compiler with fine-grained semantic judgment of an LLM agent . The entire pipeline operates with only a small set of seed instructions as input, and requires *no human annotation* or *gold references*, all while being driven by accessible, medium-sized models.

Experiments across multiple backbones and benchmarks demonstrate that *CodeEvo* significantly outperforms established data synthesis methods. Remarkably, *CodeEvo* achieves better performance than competing approaches using several times more data, indicating the superiority of our targeted, feedback-driven synthesis over sheer data volume. Our primary contributions are as follows:

- We propose *CodeEvo*, an interaction-driven synthesis framework that systematically lifts the quality of code-centric synthetic data from both the instruction and code perspectives.
- We introduce an innovative hybrid feedback mechanism that effectively combines the determinism of compiler verification with the generative flexibility of LLM agents.
- Through extensive experiments and analysis, we share insights into the key attributes, including quality, diversity, scalability, and difficulty of synthetic code data.

2 Related Works

LLM-based Agents Interaction. The interactive capabilities of language agents [12], whether with other agents or the environment, have garnered significant attention [13]. These interactions allow for complex problem-solving approaches such as collaboration [9, 14] or role-playing [15, 16], which have proven effective in diverse applications like software engineering [10, 17]. Recently, researchers have begun to explore using such interaction for various data generation, including instructions [18], reasoning chains [19], and environment-aware trajectories [20, 21]. Leveraging interaction for flexible and scalable data construction is emerging as a promising direction [22, 23]. This work takes an initial step toward applying interaction to instruction-code synthesis.

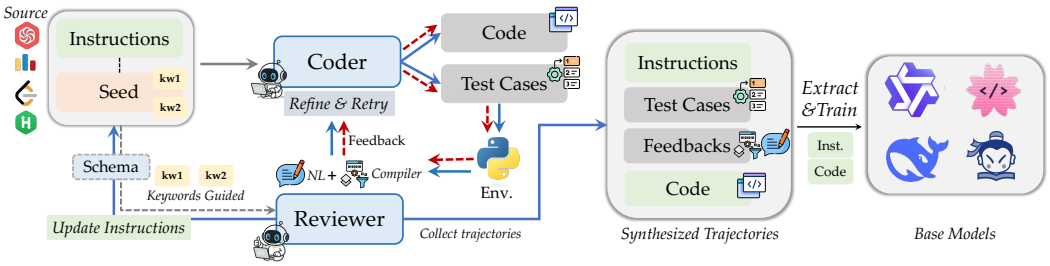
Code-centric Data Synthesis. The synthesis of instruction-code data traces back to early symbolic augmentation methods [4, 5], which augment existing code using program transformations. Recent efforts move beyond static heuristics and leverage LLMs to generate instruction-code pairs at scale with prompting [24, 25, 26], as well as through human-in-the-loop interactions [27]. Typically, WizardCoder [6] extends Evol-Instruct [8] into code data synthesis, Magicoder [28] and WaveCoder [29] derive pairs from open-source code snippets. Further, researchers lay emphasis on executable synthe-

sis [30, 31, 32, 33], using code syntax relationships [34] and unit tests [35, 36] to curate code-centric data. However, existing synthesis methods often rely on pre-defined and limited prompting heuristics, require existing code references, and largely overlook functional correctness.

Compiler Feedback in Code Generation. A key differentiator between symbolic language and natural language is executability [37], with compilers serving as a fundamental verifier [38]. In the context of LLM-based code generation, leveraging compiler feedback to improve output quality has become an active area of research. Early approaches primarily focused on post-hoc error correction using compiler signals [39], later evolving to incorporate immediate compiler feedback during generation to improve first-pass correctness [38]. Static analysis has also been explored to enrich the semantic understanding of code [40]. More recent efforts have begun decomposing complex generation tasks into subtasks, using compiler feedback for fine-grained optimization [41], debugging [42], or repo-level learning [43]. In addition, compiler feedback has also been leveraged to model preferences [44]. While compilers are widely used in the generation stage, their role in the data synthesis pipeline is underexplored. In our synthesis loop, an LLM agent interprets compiler feedback to ensure data quality and guide refinement.

3 *CodeEvo*

We detail the framework of *CodeEvo* in this section, emphasizing its core components and systematic workflow, as illustrated in Figure 2.



(a) Interaction-Driven Synthesis (b) Downstream Application

Figure 2: Overview of the *CodeEvo* framework. The synthesis process begins with seed instructions from different sources. Through continuous interaction, the Coder and Reviewer agents collaboratively construct trajectories of instruction, solution, validation, and refinement. The loop marked with → illustrates the flow of data synthesis, where new instructions are derived and paired with validated code. The loop marked with → captures the validation cycle, incorporating natural language and compiler feedback to guide refinement. Instruction-code pairs are extracted from the validated trajectories and used for downstream model training.

3.1 Preliminary

Problem Definition. Given a seed dataset S, containing initial instructions s, each with an associated set of keywords T. The goal is to synthesize an expanded dataset Q. *CodeEvo* consists of two LLM-powered agents:

- **Coder**: Generate candidate solutions and test cases for a given instruction, and refine its solution based on external feedback.
- **Reviewer**: Generate new instructions and evaluate candidate solutions, providing feedback for refinement or data selection.

Seed Instructions. In contrast to prior work that relies on golden code solutions or ready-made test cases, *CodeEvo* requires *only a lightweight set of natural language instructions*, which can originate from any domain where the problem descriptions admit symbolic solutions, such as algorithmic problems from programming platforms, NL2Code training sets, or mathematically structured problems.

3.2 Schema-Guided Instruction Generation

A central challenge in instruction synthesis is maintaining semantic control during evolution. Prior methods often rely on abstract commands (*e.g.*, "make it harder"), which can lead to vague or ungrounded content. To move beyond such abstract heuristics, we introduce Schema-guided instruction generation. This approach transforms synthesis into a principled design process. Guided by task-specific keywords, our Reviewer agent first generates a Schema—a structured blueprint that outlines the logic for combining concepts, the desired complexity, and the overall goal for a new instruction. By first formulating this design plan before generating the final text, we ensure that new instructions are not only more challenging but also logically coherent and well-grounded.

Specifically, for each seed instruction s and a selected keyword subset $t \subseteq T$, the generation process unfolds in two stages. First, the Reviewer agent formulates a Schema that serves as a detailed plan for the new instruction:

$$\text{Schema} = \text{GenerateSchema}(s, t) \quad (1)$$

Subsequently, it generates the new instruction s' by executing the plan laid out in the Schema:

$$s' = \text{GenInstruction}(s, \text{Schema}) \quad (2)$$

Crucially, this Schema-driven mechanism is inherently bidirectional. The Schema can strategically plan to either integrate keywords for added complexity or selectively omit them to construct a simplified variant, particularly when a task proves intractable for the Coder agent. This structured approach marks a significant shift from rigid prompting heuristics: enabling the generation of novel, diverse instructions while reducing the likelihood of producing unanswerable ones (statistics in Appendix H). An adaptive keyword sampling strategy is detailed in Appendix F.

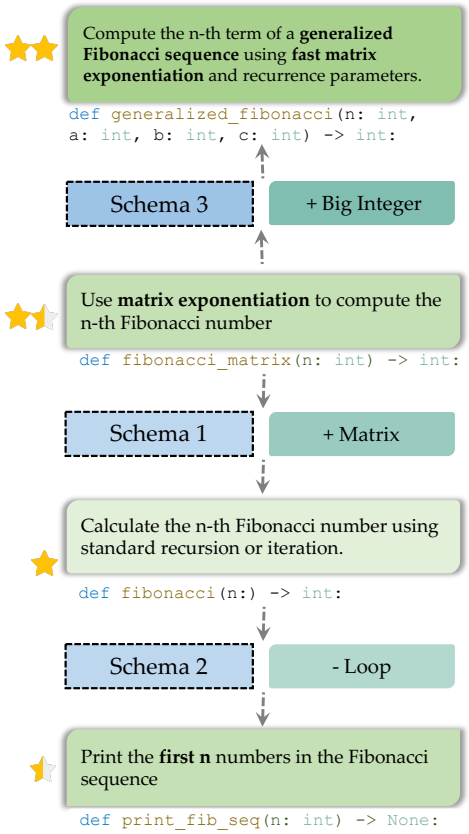


Figure 3: Illustration of transforming a seed into relevant instructions by leveraging schema and keywords.

3.3 Hybrid Feedback for Validation and Refinement

A key novelty of *CodeEvo* is our hybrid feedback mechanism, which combines deterministic compiler evaluations with generative natural language assessments to ensure the robustness and correctness of synthesized solutions. Given a transformed instruction s', the Coder first generates a candidate solution c along with initial test cases g :

$$(c, g, f_{\text{comp}}) = \text{Coder}(s') \quad (3)$$

While f_{comp} provides deterministic pass/fail signals, its utility is limited. The raw compiler output can be misleading due to insufficient test coverage and is often verbose. To overcome this, our key advantage lies in empowering the Reviewer agent to act as an intelligent judge, It moves beyond the raw signal to produce a rich, NL-based evaluation f_{NL} which scrutinizes the solution's logical alignment with the instruction, the correct implementation of specified keywords, and subtle flaws suggested by runtime behavior (*e.g.*, warnings). These two signals are then fused into a single hybrid feedback:

$$f_{\text{hybrid}} = \text{Reviewer}(f_{\text{comp}}, f_{\text{NL}}) \quad (4)$$

The hybrid feedback f_{hybrid} serves a dual role in *CodeEvo*: (1) Determining whether the current instruction-code pair should be retained or discarded. (2) Providing a rich supervisory signal that is returned to the Coder, guiding further refinement of the solution. f_{hybrid} enables iterative improvement of synthesized data without relying on external labels or human-crafted references.

Algorithm 1 Single-Seed Lifecycle in *CodeEvo*.

Require: Seed instruction s, keyword set T, maximum iterations N
Ensure: Validated instruction-code pairs Q_s

Initialize $Q_s \leftarrow \varnothing$, $q \leftarrow s$, $k \leftarrow 0$
while $k < N$ **do**
  $(c, g, f_{\text{comp}}) \leftarrow \text{Coder}(q)$
  $f_{\text{NL}} \leftarrow \text{Reviewer}(q, c, g, f_{\text{comp}})$
  $f_{\text{hybrid}} \leftarrow \text{Reviewer}(f_{\text{comp}}, f_{\text{NL}})$
  if f_{hybrid} is valid **then**
    Add (q, c) to Q_s
    Sample keywords $t \subseteq T$
    Schema $\leftarrow$ Reviewer.Plan(q, t); $q^+ \leftarrow$ Reviewer.Write(q, Schema)
    $q \leftarrow q^+$
    $k \leftarrow k + 1$
  else
    Sample keywords $t' \subseteq T$
    Schema $\leftarrow$ Reviewer.Plan(q, t'); $q^- \leftarrow$ Reviewer.Write(q, Schema) ▷ Plan a simpler variant
    $(c, g, f_{\text{comp}}) \leftarrow \text{Coder}(q^-)$
    $f_{\text{NL}} \leftarrow \text{Reviewer}(q^-, c, g, f_{\text{comp}})$
    $f_{\text{hybrid}} \leftarrow \text{Reviewer}(f_{\text{comp}}, f_{\text{NL}})$
    if f_{hybrid} is valid **then**
      Add (q^-, c) to Q_s
    end if
    break
  end if
end while
return Q_s

3.4 Interaction-Driven Synthesis

With these mechanisms, *CodeEvo* orchestrates a collaborative refinement loop between the Coder and Reviewer. This transforms data synthesis from a static, one-shot pipeline into an adaptive process where tasks are proposed, attempted, and rigorously assessed . Crucially, the framework can dynamically adjust difficulty: if a task proves too challenging, the Reviewer can formulate a simpler Schema to generate a more tractable problem (as shown in Algorithm 1). This self-correcting loop of validation and refinement provides intrinsic quality control, which is key to maintaining a high yield of valid data. This generates a rich interaction trajectory capturing the full cycle of problem-solving, feedback, and correction, from which high-quality instruction-code pairs can be extracted.

4 Experiments

4.1 Experimental Settings

Model Settings. We evaluate our approach under two backbone agent scales: a medium-scale setting with moderately sized coder and reviewer agents, and a large-scale setting with substantially larger agent pairs. In the medium-scale configuration, we employ Qwen2.5-Coder-32B-Instruct [45] as the coder agent and Qwen2.5-32B-Instruct [46] as the reviewer agent within the data synthesis pipelines of *CodeEvo*. For the large-scale configuration, we adopt gpt-oss-120B [47] as both the coder and reviewer agents.

To assess the performance improvements introduced by *CodeEvo* in code generation, we conduct experiments primarily on Qwen3-8B [48], representing general-purpose LLMs, and Qwen2.5-7B-Instruct [45], representing specialized CodeLLMs. Results on additional model backbones are provided in Appendix D. All inference and training is performed as full fine-tuning on interconnected clusters of 8 × A100 80GB GPUs, with more implementations details provided in Appendix A.

Evaluation Benchmarks. We evaluate the Python code generation capability of models trained on *CodeEvo* data using HumanEval [49], MBPP [50], and their plus versions from EvalPlus [7]. To further assess generalization under realistic difficulty levels, we also use BigCodeBench [51] and LiveCodeBench [52] which include more complex instructions, algorithmic logic, and function calls. Further experimental details can be found in Appendix B.

4.2 Baseline Construction

Baselines. As a pioneering study in synthesizing code-centric data, we leverage the following baselines to demonstrate the superiority of *CodeEvo*.

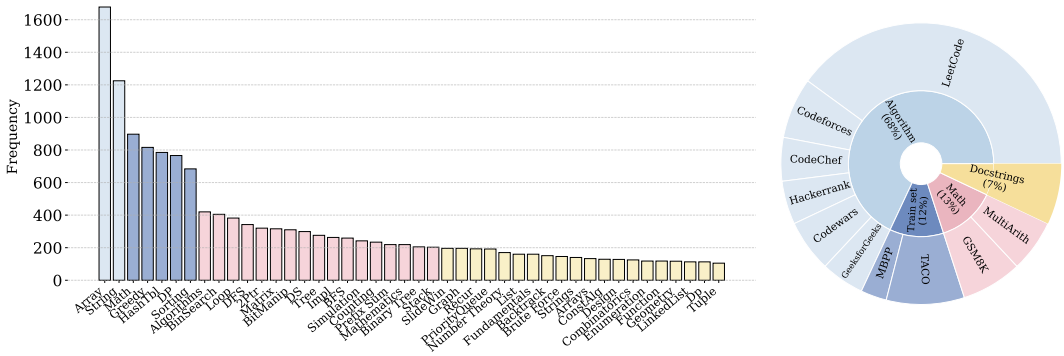
- **Zero-Shot**: The original evaluation setting using zero-shot prompting.
- **Code Evol-Instruct**: Proposed by WizardCoder [6], Code Evol-Instruct first evolves task complexity and then generates the code solutions via prompting. As the original dataset is not publicly available, we reproduce this baseline under the same setting as *CodeEvo*. The same seed data as *CodeEvo* is used to ensure a fair comparison.[2]
- **OSS-Instruct**: Released alongside Magicoder [28], OSS-Instruct derives related instructions from open-source code snippets written by humans and includes 75K samples.

Details of the baseline construction are provided in Appendix C. All these data and resources will be made public to accelerate future research.

4.3 Seed Instructions

We curate a set of ≈ 5K seed instructions from diverse sources, including programming platforms such as LeetCode and Codeforces, as well as existing math and code training sets [53, 50]. A subset of these instructions is collected alongside their corresponding reference solutions; following Luo et al. [6], we include them during training with appropriate ablation.

Each seed instruction is paired with a set of keyword tags (averaging 3 per instruction), which are either inherited from the original sources (*e.g.*, LeetCode tags, MBPP annotations) or assigned automatically when unavailable. Figure 4 provides an overview of the seed data used in our experiments. Additional statistics, balanced sampling strategy, and implementation details are in Appendix F.



(a) Distribution of keywords with occurrence frequency ≥ 100.

(b) Type and source of seeds.

Figure 4: An overview of seed instructions.

[2]We refer to this setting as `Evol-Instruct` in the following experiments for brevity.

4.4 Main Results

Performance Gains across Benchmarks. As shown in Table 1, models fine-tuned on *CodeEvo* data consistently outperform all baselines. This strong performance is evident across data synthesized from both our medium-scale (32B) and large-scale (120B) agent configurations, highlighting the framework's robustness and scalability.

Remarkably, our schema-driven method empowers even medium-sized models to produce superior data. The 17K samples generated by our 32B agents provide a greater performance boost to Qwen3-8B than the 75K OSS-Instruct dataset, further raising the LiveCodeBench score. This demonstrates that a superior synthesis algorithm can be more critical than the sheer volume of data.

Method	Data Scale	HumanEval		MBPP		BigCodeBench-Full		BigCodeBench-Hard		LiveCodeBench
		HE	*HE+*	*MBPP*	*MBPP+*	*Instruct*	*Complete*	*Instruct*	*Complete*	*v6*
Qwen2.5-Coder-7B-Instruct	-	84.1	**79.9**	79.1	66.7	40.4	48.8	18.2	21.6	17.1
OSS-Instruct	75K	83.5	78.0	78.0	64.8	41.4	48.6	**20.3**	20.3	18.9
Coder: Qwen2.5-Coder-32B-Instruct | Reviewer: Qwen2.5-32B-Instruct										
Evol-Instruct	25K	83.5	78.0	79.1	66.9	40.6	51.4	15.5	22.3	14.5
CodeEvo	17K	85.3	79.9	81.2	68.5	41.9	52.2	17.6	26.4	22.3
Coder: GPT-OSS 120B | Reviewer: GPT-OSS 120B										
Evol-Instruct	25K	85.1	80.5	81.2	69.7	42.0	**50.3**	19.7	**23.6**	22.5
CodeEvo	17K	**86.4**	**80.9**	**83.0**	**73.2**	**43.4**	50.1	**21.5**	22.9	**24.3**
Qwen3-8B	-	82.9	77.4	80.7	70.9	42.7	49.2	14.9	22.3	39.1
OSS-Instruct	75K	84.1	78.5	79.8	67.5	42.9	50.3	15.7	24.1	36.3
Coder: Qwen2.5-Coder-32B-Instruct | Reviewer: Qwen2.5-32B-Instruct										
Evol-Instruct	25K	79.2	74.6	77.5	67.2	41.5	47.7	12.3	20.9	36.1
CodeEvo	17K	83.7	76.4	81.7	72.9	42.9	50.3	14.7	21.1	39.8
Coder: GPT-OSS-120B | Reviewer: GPT-OSS-120B										
Evol-Instruct	25K	84.5	78.2	82.4	72.5	44.1	**53.3**	16.5	**25.2**	40.9
CodeEvo	17K	**86.7**	**79.8**	**85.5**	**74.1**	**44.9**	52.5	**18.3**	24.1	**42.7**

Table 1: Results of pass@1(%) performance on various models on HumanEval(+), MBPP(+), BigCodeBench-Full, BigCodeBench-Hard, and LiveCodeBench.

Interestingly, larger gains can be observed on HE+ and MBPP+, which feature extra test cases, suggesting that our "compiler-in-the-loop" design in the hybrid feedback plays a critical role in validating functional correctness. Notably, ablation results show that removing all solutions in seeds does not lead to a notable performance drop, indicating that our grounded synthesis pipeline is robust even when fully automated.

Superior Data Efficiency. Despite using fewer training examples, *CodeEvo* outperforms other approaches, which rely on 4–5× more synthetic data and code references. It further underscores the importance of quality-aware code data construction.

The efficiency stems from innovations on both sides of the pipeline: instruction synthesis is grounded through keyword-driven refinement, while code synthesis is constrained by hybrid feedback. *CodeEvo* inherently reduces the production of invalid or redundant samples, paving the way for more data-efficient enhancement of code generation capabilities. Further discussions on the impact of data scale are presented in Section 5.4.

Ablation Studies. We perform an ablation study to isolate the effect of seed data. The results in Table 2 demonstrate that its exclusion does not lead to a significant performance degradation. In certain scenarios, models trained exclusively on *CodeEvo*-synthesized data achieve even superior performance. This further suggests

Method	HE+	MBPP+	BigCodeBench-Full	
			Instruct	*Complete*
Qwen2.5-Coder-7B-Instruct				
CodeEvo w/o Seed	80.7	71.9	42.7	**51.3**
CodeEvo	**80.9**	**73.2**	**43.4**	50.1
Qwen3-8B				
CodeEvo w/o Seed	**80.1**	73.9	44.1	**52.9**
CodeEvo	79.8	**74.1**	**44.9**	52.5

Table 2: Ablation study. Use gpt-oss-120B for both coder and reviewer.

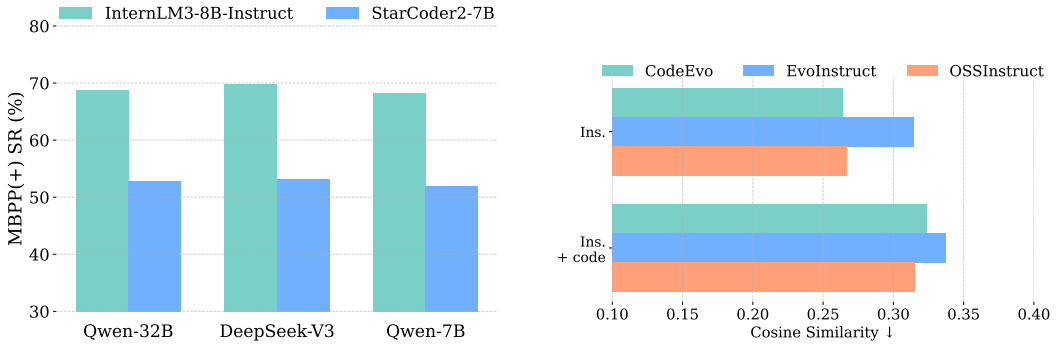
that the varied and high-quality data synthesized by *CodeEvo* provides a more effective training signal than the original seed set, which is inherently more limited in its diversity and scope.

5 Analysis

Beyond performance gains, we conduct a series of analyses to provide insights into the quality, diversity, scalability, and utility of synthetic code data.

5.1 Impact of Model Scale on Synthesis Quality

Underscoring the framework's accessibility and resource efficiency, our main experiments employ agents backed by two 32B, medium-sized models. This choice stands in contrast to methods reliant on massive-scale or proprietary LLMs [28, 30]. To analyze the framework's sensitivity to agent capability, we then conduct a set of controlled experiments using smaller (Qwen2.5-7B-Instruct) and larger (DeepSeek-V3, 671B) backbones for the Reviewer in *CodeEvo*.



(a) Success rates of InternLM3 and StarCoder2 after training with data synthesized through agents with different backbones.

(b) Comparison of instruction diversity and instruction-code pairs diversity among different synthetic methods.

Figure 5: A comparison of model performance and data diversity from different synthesis methods.

As shown in Figure 5a, data synthesized by agents of varying scales consistently boosts downstream models. Notably, even data from the 7B agent provides good performance gain, proving the efficacy of our core mechanisms—keyword-guided evolution and hybrid feedback. This result confirms that *CodeEvo* is an effective synthesis engine in its own right, enabling high-quality data synthesis without huge / proprietary models.

5.2 Synthetic Data Diversity

A core feature of *CodeEvo* is the generation of diverse instructions and preventing overfitting to narrow problem types. To assess this, we perform a comparative diversity analysis of instruction samples and instruction-code pairs (N=1000). We compute the average pairwise cosine similarity over code embeddings[3] to assess diversity.

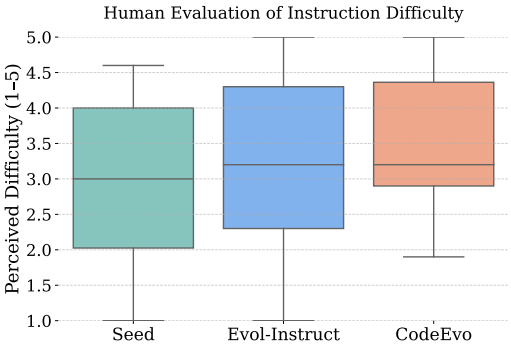
As shown in Figure 5b, *CodeEvo* achieves the lowest average similarity among instruction samples, demonstrating the effectiveness of our keyword-guided strategy in constructing semantically diverse prompts. For instruction-code pairs, the diversity of *CodeEvo* is also comparable to OSS-Instruct, which derives data directly from human-written code. This indicates that, despite undergoing a rigid filtering process, our synthesized data retains a high level of overall diversity.

5.3 Instructions Difficulty

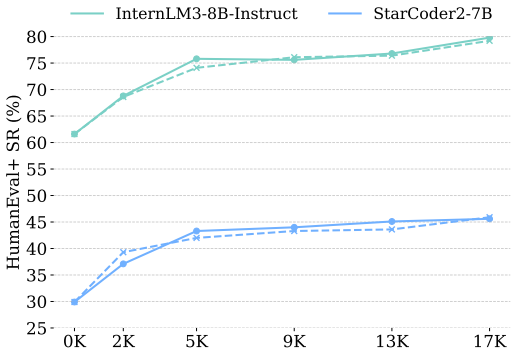
To evaluate whether *CodeEvo* really generates more challenging instructions, we conducted a human study comparing three variants derived from the same seed: the original seed instruction, an "evolved"

[3]We leverage `text-embedding-3-small` to obtain embeddings.

version from Evol-Instruct, and the instruction synthesized by *CodeEvo*. Five participants with programming experience are invited to rate the perceived difficulty of each instruction on a scale from 1 (very easy) to 5 (very difficult).



(a) Human-rated difficulty of instructions.



(b) Impact of the scale of *CodeEvo* data. Solid lines and dashed lines indicate training with and without code references of seed data, respectively.

Figure 6: Analysis of instruction difficulty and the impact of data scale.

As shown in Figure 6a, *CodeEvo* instructions received the highest difficulty scores (mean ≈ 3.5), followed by Evol-Instruct and Seed. In addition, *CodeEvo* exhibits a higher lower bound, indicating that the generated instructions are not only more difficult on average, but also more consistently fall within a higher difficulty range, which further validates the edge of using keyword guidance as an signal. In contrast, Evol-Instruct fails to consistently increase instruction difficulty.

5.4 Impact of Synthetic Data Scale

We investigate the scaling properties of *CodeEvo*-synthesized data. Two backbones are fine-tuned with incrementally larger subsets of our synthesized dataset (along with seed data), with the performance trend demonstrated in Figure 6b.

It can be observed that model performance improves steadily as more synthetic code is added. Importantly, this trend holds regardless of whether the training includes only syntactic data or a mixture of original and synthetic code. The results suggest that the *CodeEvo*-generated data does not introduce distributional shifts or performance degradation during scaling.

5.5 Data Survival Rate

We analyze the data survival rate, defined as the proportion of newly synthesized samples that pass both compiler checks and LLM-based evaluation. As shown in Figure 7, only a small fraction of the data is finally retained, and the survival rate steadily decreases across synthesis rounds.

This decline is both expected and desirable. First, the generated instructions become progressively more challenging, reaching the limits of the agent's capability. Second, unlike prior work that accepts instruction-code pairs after a single pass, we selectively retain high-quality, grounded data.

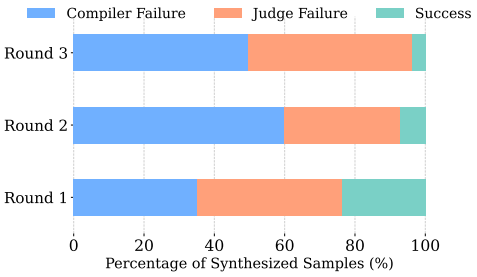


Figure 7: Synthetic data survival analysis.

6 Conclusion

In this work, we introduce *CodeEvo*, a novel framework that leverages LLM agent interactions to synthesize high-quality instruction-code pairs. To address the shortcomings of ungrounded synthetic data, *CodeEvo* employs two key mechanisms: (1) a schema-driven synthesis, where a Reviewer

agent constructs a keyword-guided Schema to serve as a blueprint for a new problem's logic and complexity, and (2) a hybrid feedback loop that integrates compiler determinism with agent-based evaluation for quality control. Extensive evaluations demonstrate that models trained on *CodeEvo* data notably outperform established baselines. We find the synthesis framework's design is a critical factor, enabling even medium-sized models to generate data that surpasses larger-scale baselines. This work offers valuable insights into effective data synthesis, moving us a step closer to democratizing advanced code intelligence.

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A Model and Training Details

To validate that our method can generalize to different LLM architectures and paradigms, we experimented with four widely used base models.

InternLM3-8B-Instruct InternLM3-8B-Instruct is a typical general-purpose large language model. It follows the architecture of its predecessor models [54] and is trained on 4 trillion high-quality tokens to support superior capabilities in multiple domains. It also supports long context understanding and CoT reasoning. In our experiment, we use this model to validate that our pipeline can improve the coding performance of general-purpose instruction-tuned models.

Qwen2.5-Coder-7B-Instruct Qwen2.5-Coder-7B-Instruct [45] is an instruction-tuned language model specifically enhanced for coding tasks. It builds upon the architecture of its general-purpose base model, Qwen2.5 [46], inheriting its computational efficiency and versatile vocabulary. To ensure the integrity of code understanding and generation, the model also incorporates several special tokens explicitly designed for code block generation. The model is trained on over 18 trillion tokens and incorporated extensive post-training technique, making it an ideal test bed for us to evaluate our method on coding LLMs that is transformed from general LLMs.

DeepSeek-Coder-6.7B-Instruct DeepSeek-Coder-6.7B-Instruct [55] is an instruction-tuned codeLLM based on the architecture of the Deepseek model [56]. It is trained on a corpus of 2 trillion tokens, extracted through a meticulously designed pipeline tailored for coding data. Compared to general-purpose LLMs, it employs a relatively small vocabulary specifically optimized for

code-related tasks. In our experiments, we adopot this model as a representative domain-specific LLM to evaluate the effectiveness of our method on coding-oriented models.

StarCoder2-7B StarCoder2-7B [57] is a representative base model from the early era of codeLLMs. It is pretrained on 3.5 trillion tokens without any additional post-training. Similar to DeepSeek-Coder, StarCoder2 employs a customized vocabulary for code-related task. We evaluate our method on this model to assess whether our trajectory data remains effective in the absence of human alignment.

For instruction-tuned models, we adopt XTuner framework [58] to streamline training. For StarCoder2-7B, we employ LLaMA-Factory [59] to conduct supervised fine-tuning. Following previous practice and our observations, we use a learning rate of 2×10^{-6} for more stable training. For the rest of models, we used a learning rate of 5×10^{-6}.

All of our models are trained on 8 × NVIDIA H800 GPUs, with a batch size of 4 per device, and a gradient accumulation of 2 steps.

B Evaluation Details

HumanEval & MBPP. HumanEval [49] and MBPP [50] are two common code completion benchmarks for evaluating the coding capability of LLMs. To further extend these two datasets, EvalPlus [7] introduced HumanEval+ and MBPP+ by adding more challenging test cases and correcting inaccurate solutions. In this study, we used both the original benchmarks (HumanEval and MBPP) and their augmented versions (HumanEval+ and MBPP+) to evaluate models trained on our data as well as baseline models. We employed the official EvalPlus implementation to evaluation both benchmarks and reported 0-shot results for all variants. Release under MIT License.

BigCodeBench. BigCodeBench [51] is a challenging benchmark for code generation, aimed at evaluating models' ability to interpret complex instructions and invoke diverse external libraries correctly. Under the completion setting, each task provides a function signature and docstrings, requiring the model to generate the full function implementation. Under the instruction setting, models are required to generate corresponding code according to a given instruction. A unit test is also provided to verify functional correctness. Spanning a broad range of practical programming scenarios, BigCodeBench assesses models on real-world tasks that demand precise understanding of task-specific APIs and library usage. It is released under the Apache License 2.0.

LiveCodeBench. LiveCodeBench [60] is a comprehensive coding benchmark curated from mainstream competition programming platforms. It aims to provide an up-to-date, contamination-free evaluating testbed, and is continuously updated with new versions that aggregate additional problems over time. In our experiments, we use the *release_v6* version of the dataset, which comprises 1055 problems collected between May 2023 and Apr 2025.

C Details of Baselines

C.1 Evol Instruct

We follow the Evol-Instruct baseline implementation used in WizardCoder [6]. To ensure a fair comparison with *CodeEvo*, we reproduce this baseline under the same experimental setup: Qwen2.5-32B-Instruct is used to generate instructions, and Qwen2.5-Coder-32B-Instruct is used to synthesize the corresponding code solutions. We adopt the same prompt heuristics as in the original implementation, where each seed is expected to produce five instruction–code pairs. The same set of seed data as used in *CodeEvo* is employed, and the seed instructions are included in the fine-tuning process.

C.2 OSS-Instruct

We leverage OSS-Instruct [28] from Magicoder as another strong baseline. Specifically, we directly use the full 75K dataset released by the authors and perform fine-tuning under the same hyperparameter settings as used for *CodeEvo*.

D Results on Additional Backbones

To further validate the effectiveness of our method, we conduct the main experiment on 3 additional backbones: InternLM3-8B-Instruct [54], StarCoder2-7B [57] and DeepSeek-Coder-6.7B-Instruct [55]. We used the medium-scale agent configuration (Qwen2.5-Coder-32B-Instruct + Qwen2.5-32B-Instruct) in this additional experiment. The results are shown in Table 3. We can easily see that our method outperforms most of the baselines on all backbones.

Method	Data Scale	HumanEval		MBPP		BigCodeBench-Full		BigCodeBench-Hard		LiveCodeBench
		HE	*HE+*	*MBPP*	*MBPP+*	*Instruct*	*Complete*	*Instruct*	*Complete*	*v6*
InternLM3-8B-Instruct	-	64.0	61.6	64.8	54.5	26.4	41.3	10.14	12.20	16.0
Evol-Instruct	25K	68.3	64.6	72.4	62.7	31.5	39.5	12.84	14.90	14.9
OSS-Instruct	75K	80.5	71.4	80.4	70.4	30.1	40.2	14.19	14.90	15.4
CodeEvo	17K	**82.3**	**78.0**	**81.2**	**71.4**	**34.9**	**43.2**	**15.54**	**15.50**	**17.1**
StarCoder2-7B	-	35.4	29.9	54.4	45.6	8.8	10.7	0.6	4.1	0.6
Evol-Instruct	25K	45.7	42.7	60.6	51.3	29.2	33.2	8.1	6.1	10.9
OSS-Instruct	75K	**50.6**	43.9	60.3	49.7	29.7	31.4	7.4	6.8	**12.6**
CodeEvo	17K	50.0	**44.5**	**66.4**	**55.6**	**30.3**	**34.6**	**8.8**	**10.8**	**12.6**
DeepSeek-Coder-6.7B-Instruct	-	74.4	68.9	74.3	65.6	34.6	43.4	9.5	16.9	14.3
Evol-Instruct	25K	75.0	68.3	74.9	64.6	35.8	**44.6**	**12.8**	16.9	13.1
OSS-Instruct	75K	76.8	70.7	**77.2**	64.6	36.4	43.8	12.2	11.5	14.9
CodeEvo	17K	**77.4**	**71.3**	**77.2**	**65.9**	**37.5**	43.8	**12.8**	**18.2**	**17.7**

Table 3: Extended results on additional backbone models (directly using keywords). All results are reported with pass@1(%) performance.

E Code Synthesis Details

The prompts we used for agent collaboration are in Prompt 8.

F Seed Instructions and Keywords

We collect instruction data from a variety of public coding platforms, including

- LeetCode: `https://leetcode.com/`
- Codeforces: `https://codeforces.com/`
- Codewars: `https://www.codewars.com/`
- GeeksforGeeks: `https://www.geeksforgeeks.org/`
- CodeChef: `https://www.codechef.com/`

We conduct a thorough similarity check and confirm that there is no contamination with the evaluation benchmarks. No personally identifiable information is present in the dataset.

The prompt used for keyword generation is provided in Prompt 9, and the keyword sampling algorithm is detailed in Algorithm 2.

G Details of Ablation Studies

In addition to Table 2, we provide the complete results of ablation studies in Table 4 that covers more benchmarks.

H Extended Analysis

H.1 Impact of Model Scale

Beyond the MBPP+ experiments covered in Section 5.1, we further demonstrate the scale of agent backbones' influence on downstream results, as shown in Figure 10.

Prompt for Generating CodeEvo Trajectory

Coder:
Write python code to solve the following problem:
{Problem description}.
Include test case execution in your code.

Reviewer:
Next I will give you a coding problem, a piece of code, and the execution result of this code. Please determine if the code given correctly solves the problem given.
The problem is described as:
{Problem description}
The code to be assessed is:
{Code from Coder}
The output of this code during execution is:
{Outputs from execution}
The error message generated during execution is:
{Errors from execution}
First output S̈uccessör F̈ailureäs your judgement. Then explain the reasons and possible improvements. Do not give out improved codes.

Coder:
The following is an evaluation and feedback on whether the code you generated successfully answered the given question:
{Feedbacks from Reviewer}
Please use this feedback to improve your code so that it answers the question correctly. Still, output the refined code block only.

Reviewer:
Below I will give you a programming problem and its keywords, design a programming problem based on this programming problem that is knowledge related but more difficult.
You can increase the difficulty by using, but not limited to, the following methods:
{Approaches to increase problem difficulty}
Please use the following output format:
###New
New programming problem you designed
This original programming problem is described as:
{Problem description}
The keywords of the original problem are:
{Keywords of the problem}

Prompt 8: Prompts for generating CodeEvo Trajectory.

Algorithm 2 Stratified Keyword Sampling Algorithm

Require: Label set T, $m = |T|$; sampling range $[r_{\min}, r_{\max}]$; maximum sampling steps $t_{\max}$
if $m \le r_{\max}$ **then**
  for $t = 1$ to $t_{\max}$ **do**
    Randomly sample $r \sim \mathcal{U}[r_{\min}, \min(m, r_{\max})]$
    Sample a subset $S_t \subseteq T$, where $|S_t| = r$
  end for
else
  Initialize $T_{\text{remaining}} \leftarrow T$
  for $t = 1$ to $t_{\max}$ **do**
    if $T_{\text{remaining}} = \varnothing$ **then**
      break
    end if
    Let $r \sim \mathcal{U}[r_{\min}, \min(|T_{\text{remaining}}|, r_{\max})]$
    Sample $S_t \subseteq T_{\text{remaining}}$, $|S_t| = r$
    $T_{\text{remaining}} \leftarrow T_{\text{remaining}} \setminus S_t$
  end for
end if

```
Prompt for Generating Keywords for Seed Instructions
You are given a text that includes a programming problem description and
explanations of its solutions.  Your task is to identify and list the key
programming concepts, data structures, or algorithms that are central to solving the
problem.  Provide your answer as a list of keywords or tags (e.g., "Array", "Hash
Table", "Sorting", "Recursion", "Loop", "String", "Stack") that best capture the
main ideas or techniques involved.
For example, if the problem involves finding two numbers in an array that add up to
a target sum, appropriate tags might be "Array" and "Hash Table".
Now, here is the text:
{text}
Please provide the keywords for this problem as a comma-separated list (e.g.,
"Array, Hash Table").
```

Prompt 9: Prompts for generating keywords for instructions.

Method	Data Scale	HumanEval		MBPP		BigCodeBench-Full		BigCodeBench-Hard	
		HE	*HE+*	*MBPP*	*MBPP+*	*Instruct*	*Complete*	*Instruct*	*Complete*
InternLM3-8B-Instruct									
CodeEvo w/o Seed	12K	80.5	**76.8**	**81.5**	**71.4**	**34.9**	41.3	14.86	**16.20**
CodeEvo	17K	**82.3**	**76.8**	81.2	**71.4**	**34.9**	**43.2**	**15.54**	15.50
StarCoder2-7B									
CodeEvo w/o Seed	12K	**51.2**	**46.3**	64.0	52.9	29.7	33.8	**8.8**	6.8
CodeEvo	17K	50.0	44.5	**66.4**	**55.6**	**30.3**	**34.6**	**8.8**	**10.8**
DeepSeek-Coder-6.7B-Instruct									
CodeEvo w/o Seed	12K	76.2	68.9	**77.2**	**65.9**	36.0	43.4	**12.8**	**18.6**
CodeEvo	17K	**77.4**	**71.3**	**77.2**	**65.9**	**37.5**	43.4	**12.8**	16.9
Qwen2.5-Coder-7B-Instruct									
CodeEvo w/o Seed	12K	84.8	79.3	78.0	64.8	**42.0**	52.1	17.6	23.6
CodeEvo	17K	**85.3**	**79.9**	**81.2**	**68.5**	41.9	**52.2**	17.6	**26.4**

Table 4: Ablation study comparing *CodeEvo* with and without Seed Initialization across multiple backbones and benchmarks, while maintaining consistent data scale annotation.

H.2 Solvable Rate of Synthetic Instructions

As discussed, a key pitfall of synthetic code data is that newly generated instructions may be ungrounded, *i.e.*, cannot find valid solutions. We investigate this issue by conducting a manual analysis of instructions synthesized by *CodeEvo* and Evol-Instruct.

The results shown in Figure 11 reveal clear differences in solvability across the two approaches.

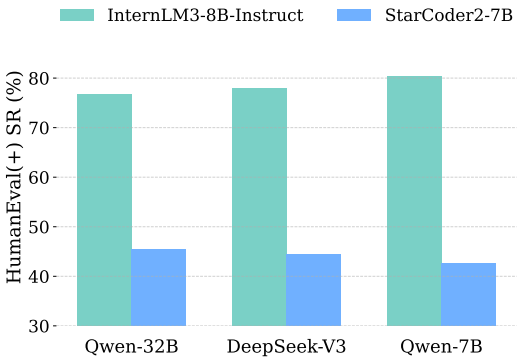

Figure 10: Success rates of InternLM3 and StarCoder2 after training with data synthesized through agents with different backbones.

Figure 11: Comparing the solvability of instructions synthesized by *CodeEvo* and Evol-Instruct.

I Human Participants

We recruit college-level participants with a background in computer science to conduct experiments in Section 5.3 and Appendix H.2. For instructions, participants are asked to follow the synthesized instructions directly as part of the evaluation process.

All participants are compensated at a rate of $10 per hour for their time and effort. We do not record any personal information, and all participants provide informed consent. The experiment does not involve surveys, interviews, or behavioral tracking.

J Case Studies

We provide two case studies of *CodeEvo* generating new instructions, as shown in Prompt 12 and Prompt 13.

```
Case of building programming problems
Seed Problem:
A permutation of an array of integers is an arrangement of its members into a
sequence or linear order.
For example, for arr = [1,2,3], the following are all the permutations of arr:
[1,2,3], [1,3,2], [2, 1, 3], [2, 3, 1], [3,1,2], [3,2,1].
The next permutation of an array of integers is the next lexicographically greater
permutation of its integer.  More formally, if all the permutations of the array
are sorted in one container according to their lexicographical order, then the
next permutation of that array is the permutation that follows it in the sorted
container.  If such arrangement is not possible, the array must be rearranged as the
lowest possible order (i.e., sorted in ascending order).
For example, the next permutation of arr = [1,2,3] is [1,3,2].
Similarly, the next permutation of arr = [2,3,1] is [3,1,2].
While the next permutation of arr = [3,2,1] is [1,2,3] because [3,2,1] does not have
a lexicographical larger rearrangement.
Given an array of integers nums, find the next permutation of nums.
The replacement must be in place and use only constant extra memory.
Generated Problem 1:
Given an array of integers ‘nums‘, find the next lexicographically greater
permutation of its integers.  If such an arrangement is not possible, rearrange
the array in ascending order.  Additionally, ensure that the solution handles arrays
with duplicate elements efficiently and outputs the result in a circular format,
where the last element points back to the first element.
Generated Problem 2:
Given a doubly linked list of integers ‘nums‘, find the next lexicographically
greater permutation of its integers.  If such an arrangement is not possible,
rearrange the list in ascending order.  The solution must handle lists with
duplicate elements efficiently and output the result in a circular format, where the
last node points back to the first node and vice versa.  Additionally, the solution
should be able to handle lists with up to 1000 nodes, where each node's value is
between 0 and 1000.
```

Prompt 12: Case Study.

```
Case of building programming problems
Seed Problem:
You are given a string S of length 6.  It is guaranteed that the first three
characters of S are ABC and the last three characters are digits.
Determine if S is the abbreviation of a contest held and concluded on AtCoder before
the start of this contest.
Here, a string T is ẗhe abbreviation of a contest held and concluded on AtCoder
before the start of this contestïf and only if it equals one of the following 348
strings:
ABC001, ABC002, ..., ABC314, ABC315, ABC317, ABC318, ..., ABC348, ABC349.
Note that ABC316 is not included.
Input
The input is given from Standard Input in the following format:
S
Output
If S is the abbreviation of a contest held and concluded on AtCoder before the start
of this contest, print Yes; otherwise, print No.
Constraints
- S is a string of length 6 where the first three characters are ABC and the last
three characters are digits.
Generated Problem 1:
You are given a string S of length 6.  It is guaranteed that the first three
characters of S are ABC and the last three characters are digits.  Determine if S
is the abbreviation of a contest held and concluded on AtCoder before the start
of this contest, considering that some contest numbers were skipped due to special
events.  Specifically, the valid contest numbers are ABC001 through ABC314, ABC315,
ABC317 through ABC348, and ABC349.  Note that ABC316 is not included.  Additionally,
validate the input to ensure it strictly follows the format and handle any invalid
inputs gracefully.
Generated Problem 2:
You are given a string S of length 6.  It is guaranteed that the first three
characters of S are ABC and the last three characters are digits.  Determine if S
is the abbreviation of a contest held and concluded on AtCoder before the start
of this contest, considering that some contest numbers were skipped due to special
events.  Specifically, the valid contest numbers are ABC001 through ABC314, ABC315,
ABC317 through ABC348, and ABC349.  Note that ABC316 is not included.  Additionally,
validate the input to ensure it strictly follows the format and handle any invalid
inputs gracefully.  Furthermore, if the input is valid but the contest number is a
multiple of 7, print S̈pecial Caseïnstead of Ÿes.̈
Generated Problem 3:
You are given a string S of length 6.  It is guaranteed that the first three
characters of S are ABC and the last three characters are digits.  Determine if S
is the abbreviation of a contest held and concluded on AtCoder before the start
of this contest, considering that some contest numbers are missing due to special
events.  Specifically, the valid contest numbers are all integers from 001 to 349
except for 316.  Additionally, validate the input to ensure it strictly follows the
format and handle any invalid inputs gracefully by printing Ïnvalid Input.̈
```

Prompt 13: Case Study.