```
# pyproject.toml.jinja

[project]
name = "hw03"
version = "0.1.0"
description = "MNIST CNN"
readme = "README.md"
authors = [
    { name = "Wongee (Freddy) Hong", email = "wongee.hong@cooper.edu" }
]
requires-python = ">=3.11"
dependencies = [
    "structlog",
    "numpy",
    "tensorflow",
    "tensorflow_datasets",
    "pydantic-settings",
    "matplotlib",
    "tqdm",
    "jax",
    "jaxlib",
    "flax",
    "optax",
    "scikit-learn",
]

[project.scripts]
hw03 = "hw03:main"

[build-system]
requires = ["uv_build>=0.8.3,<0.9.0"]
build-backend = "uv_build"
```

```python
import logging
import os
import sys
from pathlib import Path

import jax
import numpy as np
import structlog


class FormattedFloat(float):
    def __repr__(self) -> str:
        return f"{self:.4g}"


def custom_serializer_processor(logger, method_name, event_dict):
    for key, value in event_dict.items():
        if hasattr(value, "numpy"):
            value = value.numpy()
        if isinstance(value, jax.Array):
            value = np.array(value)
        if isinstance(value, (np.generic, np.ndarray)):
            value = value.item() if value.size == 1 else value.tolist()
        if isinstance(value, float):
            value = FormattedFloat(value)
        if isinstance(value, Path):
            value = str(value)
        event_dict[key] = value
    return event_dict

def configure_logging(log_dir: Path = Path("artifacts"), log_name: str = "train.json"):
    """Console = pretty colors, File = JSON."""
    log_dir.mkdir(parents=True, exist_ok=True)
    log_file = log_dir / log_name
    log_level = os.environ.get("LOG_LEVEL", "INFO").upper()

    shared_processors = [
        structlog.stdlib.add_logger_name,
        structlog.stdlib.add_log_level,
        structlog.stdlib.PositionalArgumentsFormatter(),
        structlog.processors.TimeStamper(fmt="iso"),
        structlog.processors.StackInfoRenderer(),
        structlog.processors.format_exc_info,
        structlog.processors.UnicodeDecoder(),
        custom_serializer_processor,
    ]


    structlog.configure(
        processors=shared_processors + [

            structlog.stdlib.ProcessorFormatter.wrap_for_formatter,
        ],
        logger_factory=structlog.stdlib.LoggerFactory(),
        wrapper_class=structlog.stdlib.BoundLogger,
        cache_logger_on_first_use=True,
    )

    console_renderer = structlog.dev.ConsoleRenderer(
        colors=sys.stdout.isatty(),
        exception_formatter=structlog.dev.RichTracebackFormatter(),
    )
    console_handler = logging.StreamHandler(sys.stdout)
    console_handler.setFormatter(
        structlog.stdlib.ProcessorFormatter(

            processors=[
                structlog.stdlib.ProcessorFormatter.remove_processors_meta,
                console_renderer
```



```python
            ],
        )
    )

    file_renderer = structlog.processors.JSONRenderer()
    file_handler = logging.FileHandler(log_file, mode="w")
    file_handler.setFormatter(
        structlog.stdlib.ProcessorFormatter(
            processors=[
                structlog.stdlib.ProcessorFormatter.remove_processors_meta,
                file_renderer
            ],
        )
    )

    root_logger = logging.getLogger()
    root_logger.addHandler(console_handler)
    root_logger.addHandler(file_handler)
    root_logger.setLevel(log_level)

    logging.getLogger("matplotlib").setLevel(logging.WARNING)
    logging.getLogger("PIL").setLevel(logging.WARNING)

    return log_file
```

```python
from pathlib import Path
from typing import Tuple
from pydantic import BaseModel
from pydantic_settings import BaseSettings


class ModelSettings(BaseModel):
    input_depth: int = 1
    layer_depths: list[int] = [16,32]
    blocks_per_stage: list[int] = [1,1]
    num_classes: int = 10
    dropout: float = 0.2


class DataSettings(BaseModel):
    batch_size: int = 128
    validation_size: int = 10000
    shuffle_buffer: int = 10000


class TrainingSettings(BaseModel):
    """Settings for model training."""
    num_epochs: int = 3
    learning_rate: float = 0.005
    weight_decay: float = 1e-4                    # L2 penalty
    log_interval: int = 100


class PlottingSettings(BaseModel):
    """Settings for logging and saving artifacts."""
    output_dir: Path = Path("artifacts")
    figsize: Tuple[int, int] = (5, 3)
    dpi: int = 200


class AppSettings(BaseSettings):
    """Main application settings."""
    debug: bool = False
    random_seed: int = 31415

    model: ModelSettings = ModelSettings()
    data: DataSettings = DataSettings()
    training: TrainingSettings = TrainingSettings()
    plotting: PlottingSettings = PlottingSettings()


def load_settings() -> AppSettings:
    """Load application settings."""
    return AppSettings()
```

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{"event": "\u001b[2m2025-09-25T01:36:25.832274Z\u001b[0m [\u001b[32m\u001b[1minfo \u001b[0m] \u001b[1mFinal Test Results \u001b[0m [\u001b[0m\u001b[1m\u001b[34mhw03\u001b[0m]\u001b[0m \u001b[36mtest_acc\u001b[0m=\u001b[35m0.9683\u001b[0m \u001b[36mtest_loss\u001b[0m=\u001b[35m0.09979\u001b[0m"}

```python
import matplotlib
import matplotlib.pyplot as plt
import structlog

log = structlog.get_logger()

font = {
    # "family": "Adobe Caslon Pro",
    "size": 10,
}

matplotlib.style.use("classic")
matplotlib.rc("font", **font)

def plot_losses(train_losses, val_losses, settings):
    plt.figure(figsize=(8, 5))
    plt.plot(train_losses, label="Train Loss", alpha=0.7)
    steps_per_epoch = 50000 // settings.training.batch_size
    val_x = [i * steps_per_epoch for i in range(1, len(val_losses)+1)]
    plt.plot(val_x, val_losses, label="Validation Loss", marker="o")
    plt.xlabel("Step")
    plt.ylabel("Loss")
    plt.title("Training & Validation Loss")
    plt.legend()
    plt.grid(True)

    settings.plotting.output_dir.mkdir(parents=True, exist_ok=True)
    output_path = settings.plotting.output_dir / "Loss Graph.pdf"
    plt.savefig(output_path)
    log.info("Saved Loss Graph plot", path=str(output_path))
```

```
import optax
import structlog
from flax import nnx
import jax
import pathlib as Path

from .config import load_settings
from .logging import configure_logging
from .model import Classifier
from .training import train, test_evaluation
from .data import load_mnist

def main() -> None:
    settings = load_settings()
    log_file = configure_logging()
    log = structlog.get_logger()
    log.info("Settings loaded", settings=settings.model_dump())
    print(f"Logs are being saved to {log_file}")

    ds_train, ds_val, ds_test = load_mnist(
        batch_size=settings.data.batch_size,
        validation_size=settings.data.validation_size,
    )
    rngs = nnx.Rngs(params=settings.random_seed, dropout=settings.random_seed +
1)
    model = Classifier(
        rngs=rngs,
        input_depth=settings.model.input_depth,
        layer_depths=settings.model.layer_depths,
        blocks_per_stage=settings.model.blocks_per_stage,
        layer_kernel_sizes=[(3,3)] * len(settings.model.layer_depths),
        num_classes=settings.model.num_classes,
        dropout=settings.model.dropout,
    )

    params = nnx.state(model, nnx.Param)
    num_params = sum(p.size for p in jax.tree_util.tree_leaves(params))
    log.info("Model created", num_params=num_params)

    # LR schedule and optimizer
    train_size      = 50000
    steps_per_epoch = train_size // settings.data.batch_size
    decay_steps     = settings.training.num_epochs * steps_per_epoch
    lr_schedular = optax.schedules.cosine_decay_schedule(
        init_value=settings.training.learning_rate,
        decay_steps=decay_steps,
    )
    optimizer = nnx.Optimizer(
        model,
        optax.adamw(
            learning_rate=lr_schedular,
            weight_decay=settings.training.weight_decay,
        ),
        wrt=nnx.Param,
    )

    _ = train(model, optimizer, ds_train, ds_val, rngs)

    # Test
    log.info("Starting final testing...")
    test_loss, test_acc = test_evaluation(model, ds_test, rngs)
    log.info("Final Test Results", test_loss=test_loss, test_acc=test_acc)
```

```python
import jax
import jax.numpy as jnp
from flax import nnx

class Conv2d(nnx.Module):
    def __init__(
        self,
        in_channels: int,
        out_channels: int,
        kernel_size,
        *,
        strides=(1, 1),
        padding="SAME",
        use_bias=True,
        dropout=0.0,
        rngs: nnx.Rngs,
    ):
        self.conv = nnx.Conv(
            in_channels, out_channels, kernel_size,
            strides=strides, padding=padding, use_bias=use_bias, rngs=rngs
        )
        self.dropout = nnx.Dropout(dropout, rngs=rngs) if dropout > 0.0 else Non
e

    def __call__(self, x, *, rngs: nnx.Rngs):
        x = self.conv(x)
        if self.dropout:
            x = self.dropout(x, rngs=rngs)
        return x


class ResidualBlock(nnx.Module):
    """Basic residual block."""
    def __init__(
        self,
        in_channels: int,
        out_channels: int,
        *,
        stride=(1, 1),
        dropout=0.0,
        rngs: nnx.Rngs,
    ):
        self.norm1 = nnx.GroupNorm(num_features=in_channels, num_groups=8, rngs=
rngs)
        self.conv1 = Conv2d(
            in_channels, out_channels, (3, 3),
            strides=stride, dropout=dropout, rngs=rngs,
        )
        self.norm2 = nnx.GroupNorm(num_features=out_channels, num_groups=8, rngs
=rngs)
        self.conv2 = Conv2d(
            out_channels, out_channels, (3, 3),
            strides=(1, 1), dropout=0.0, rngs=rngs,
        )
        self.shortcut = (
            Conv2d(
                in_channels, out_channels, (1, 1),
                strides=stride, dropout=0.0, rngs=rngs,
            )
            if in_channels != out_channels or stride != (1, 1)
            else None
        )

    def __call__(self, x, *, rngs: nnx.Rngs):
        out = self.norm1(x)
        out = nnx.relu(out)
        out = self.conv1(out, rngs=rngs)

        out = self.norm2(out)
```



```python
        out = nnx.relu(out)
        out = self.conv2(out, rngs=rngs)

        identity = x if self.shortcut is None else self.shortcut(x, rngs=rngs)
        return out + identity

class ResidualStage(nnx.Module):
    def __init__(
        self,
        in_channels: int,
        out_channels: int,
        num_blocks: int,
        dropout: float,
        stride=(1, 1),
        *,
        rngs: nnx.Rngs,
    ):
        self.blocks = []
        self.blocks.append(
            ResidualBlock(
                in_channels,
                out_channels,
                stride=stride,
                dropout=dropout,
                rngs=rngs,
            )
        )
        # Rest keep stride = (1,1)
        for _ in range(1, num_blocks):
            self.blocks.append(
                ResidualBlock(
                    out_channels,
                    out_channels,
                    stride=(1, 1),
                    dropout=dropout,
                    rngs=rngs,
                )
            )

    def __call__(self, x, *, rngs: nnx.Rngs):
        for block in self.blocks:
            x = block(x, rngs=rngs)
        return x

class Classifier(nnx.Module):
    """Residual network classifier for MNIST."""

    def __init__(
        self,
        input_depth: int,
        layer_depths: list[int],
        blocks_per_stage,
        layer_kernel_sizes: list[tuple[int, int]],
        num_classes: int,
        *,
        rngs: nnx.Rngs,
        dropout: float = 0.1,
    ):
        assert len(layer_depths) == len(layer_kernel_sizes), \
            "layer_depths and layer_kernel_sizes must match in length"
        self.init_conv = Conv2d(input_depth, layer_depths[0],
                                kernel_size=layer_kernel_sizes[0],
                                strides=(1, 1), dropout=dropout, rngs=rngs)

        # Build stages
        self.stages = []
        self.blocks_per_stage = blocks_per_stage
        in_ch = layer_depths[0]
        for i, out_ch in enumerate(layer_depths):
```

```
            stride = (2, 2) if i > 0 else (1, 1)  # downsample at stage boundari
es
            num_blocks = (self.blocks_per_stage[i]
                          if self.blocks_per_stage is not None
                          else 1)
            stage = ResidualStage(
                in_channels=in_ch,
                out_channels=out_ch,
                num_blocks=num_blocks,
                stride=stride,
                dropout=dropout,
                rngs=rngs,
            )
            self.stages.append(stage)
            in_ch = out_ch

        # Final classifier head
        self.fc = nnx.Linear(in_ch, num_classes, rngs=rngs)

    def __call__(self, x, *, rngs: nnx.Rngs):
        x = self.init_conv(x, rngs=rngs)
        for stage in self.stages:
            x = stage(x, rngs=rngs)

        x = jnp.mean(x, axis=(1, 2))

        # Final logits
        return self.fc(x)
```

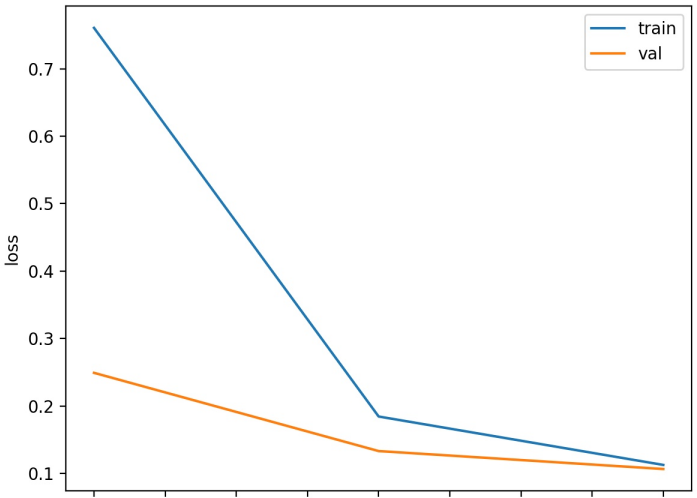
```python
import jax
import jax.numpy as jnp
import optax
from flax import nnx
import matplotlib.pyplot as plt
import structlog

from .config import load_settings

log = structlog.get_logger()

def cross_entropy_loss(logits, labels):
    return optax.softmax_cross_entropy_with_integer_labels(
        logits, labels
    ).mean()


def compute_accuracy(logits, labels):
    preds = jnp.argmax(logits, axis=-1)
    return jnp.mean(preds == labels)


def _loss_fn(model, batch, rngs):
    images, labels = batch
    labels = labels.ravel()
    logits = model(images, rngs=rngs)
    loss = cross_entropy_loss(logits, labels)
    return loss, logits


@nnx.jit
def train_step(model, optimizer, batch, rngs):
    grad_fn = nnx.value_and_grad(_loss_fn, has_aux=True)
    (loss, logits), grads = grad_fn(model, batch, rngs)
    optimizer.update(model, grads)
    return loss, logits


@nnx.jit
def eval_step(model, batch, rngs):
    loss, logits = _loss_fn(model, batch, rngs)
    return loss, logits

def evaluate(model, dataset, rngs):
    total_loss, total_acc, n_batches = 0.0, 0.0, 0
    for batch in dataset.as_numpy_iterator():
        loss, logits = eval_step(model, batch, rngs)
        _, labels = batch
        labels = labels.ravel()
        acc = compute_accuracy(logits, labels)
        loss = float(loss)
        acc = float(acc)
        total_loss += loss
        total_acc += float(acc)
        n_batches += 1
    return total_loss / max(n_batches, 1), total_acc / max(n_batches, 1)

def train(model, optimizer, train_ds, val_ds, rngs):
    settings = load_settings()
    output_dir = settings.plotting.output_dir
    output_dir.mkdir(parents=True, exist_ok=True)

    log_interval = settings.training.log_interval
    num_epochs = settings.training.num_epochs

    metrics_history = {
    "train_steps": [],
    "train_loss": [],
    "train_accuracy": [],
```

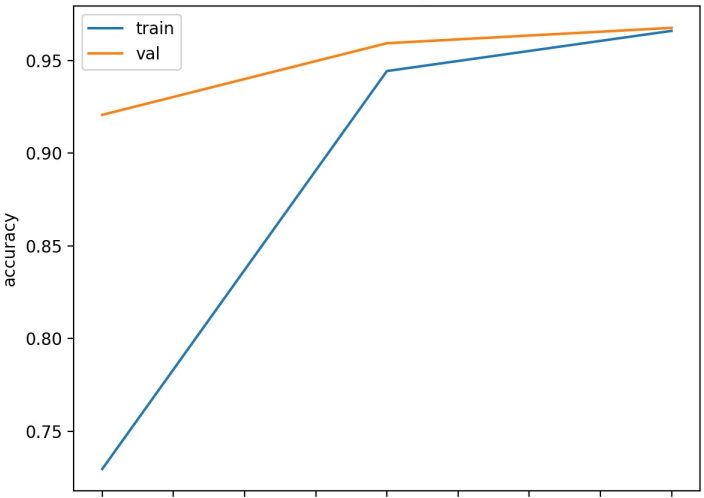


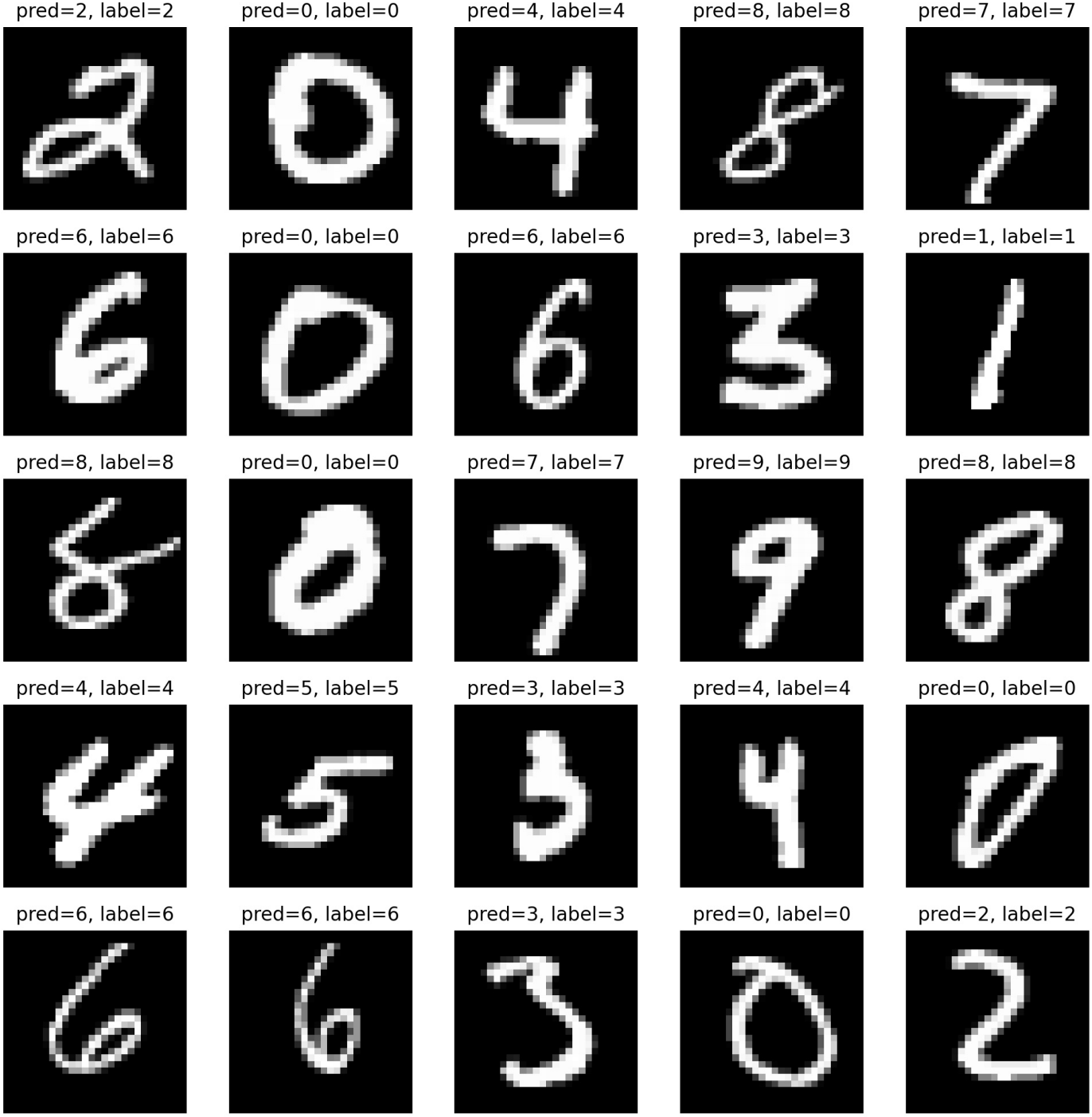
```python
    "val_steps": [],
    "val_loss": [],
    "val_accuracy": [],
}

    global_step = 0

    for epoch in range(1, num_epochs + 1):

        for batch in train_ds.as_numpy_iterator():
            loss, logits = train_step(model, optimizer, batch, rngs)

            if global_step % log_interval == 0:
                images, labels = batch
                labels = labels.ravel()
                acc = compute_accuracy(logits, labels)

                loss_val = float(loss)
                acc_val = float(acc)

                metrics_history["train_steps"].append(global_step)
                metrics_history["train_loss"].append(loss_val)
                metrics_history["train_accuracy"].append(acc_val)

                log.info(
                    "train_iter",
                    epoch=epoch,
                    step=global_step,
                    loss=loss_val,
                    acc=acc_val,
                )
            global_step += 1


        val_loss, val_acc = evaluate(model, val_ds, rngs)
        metrics_history["val_steps"].append(global_step)
        metrics_history["val_loss"].append(val_loss)
        metrics_history["val_accuracy"].append(val_acc)

        log.info(
            "epoch_summary",
            epoch=epoch,
            step=global_step,
            val_loss=val_loss,
            val_acc=val_acc,
        )

    log.info("Training finished. Generating final plots...")
    fig, (ax1, ax2) = plt.subplots(1, 2, figsize=(15, 6))

    ax1.set_title("Loss vs. Steps")
    ax2.set_title("Accuracy vs. Steps")

    ax1.plot(metrics_history["train_steps"], metrics_history["train_loss"], label="train"
, alpha=0.7)
    ax2.plot(metrics_history["train_steps"], metrics_history["train_accuracy"], label="t
rain", alpha=0.7)

    ax1.plot(metrics_history["val_steps"], metrics_history["val_loss"], label="val", m
arker='o', linestyle='--')
    ax2.plot(metrics_history["val_steps"], metrics_history["val_accuracy"], label="val
", marker='o', linestyle='--')

    ax1.set_xlabel("Step")
    ax1.set_ylabel("Loss")
    ax1.legend()
    ax1.grid(True, which='both', linestyle='--', linewidth=0.5)

    ax2.set_xlabel("Step")
```

```
    ax2.set_ylabel("Accuracy")
    ax2.legend()
    ax2.grid(True, which='both', linestyle='--', linewidth=0.5)

    fig.tight_layout()
    fig.savefig(output_dir / "final_training_metrics.png", dpi=settings.plotting.dpi)
    plt.close(fig)

    return metrics_history

def test_evaluation(model, test_ds, rngs):
    settings = load_settings()
    output_dir = settings.plotting.output_dir
    output_dir.mkdir(parents=True, exist_ok=True)

    test_loss, test_acc = evaluate(model, test_ds, rngs)
    log.info("test_results", test_loss=test_loss, test_acc=test_acc)

    test_batch = next(test_ds.as_numpy_iterator())
    _, logits = eval_step(model, test_batch, rngs)
    images, labels = test_batch
    preds = jnp.argmax(logits, axis=-1)

    fig, axs = plt.subplots(5, 5, figsize=(10, 10))
    for i, ax in enumerate(axs.flatten()):
        ax.imshow(images[i, ..., 0], cmap="gray")
        ax.set_title(f"pred={int(preds[i])}, label={int(labels[i])}")
        ax.axis("off")
    fig.tight_layout()
    fig.savefig(output_dir / "test_predictions.png", dpi=settings.plotting.dpi)
    plt.close(fig)

    return test_loss, test_acc
```

```
import tensorflow_datasets as tfds
import tensorflow as tf

def load_mnist(batch_size=128, validation_size=10000, seed=0):
    ds_train = tfds.load("mnist", split="train", shuffle_files=True, as_supervised=
True)
    ds_test  = tfds.load("mnist", split="test", as_supervised=True)

    def _preprocess(image, label):
        image = tf.cast(image, tf.float32) / 255.0
        label = tf.cast(label, tf.int32)
        return image, label

    ds_train = ds_train.map(_preprocess, num_parallel_calls=tf.data.AUTOTUNE)
    ds_test  = ds_test.map(_preprocess, num_parallel_calls=tf.data.AUTOTUNE)

    ds_val = ds_train.take(validation_size)
    ds_train = ds_train.skip(validation_size)

    ds_train = ds_train.shuffle(10 * batch_size, seed=seed).batch(batch_size).pr
efetch(tf.data.AUTOTUNE)
    ds_val   = ds_val.batch(batch_size).prefetch(tf.data.AUTOTUNE)
    ds_test  = ds_test.batch(batch_size).prefetch(tf.data.AUTOTUNE)

    return ds_train, ds_val, ds_test
```


Loss
train
val
loss
epoch
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00


Accuracy
train
val
accuracy
epoch
0.95
0.90
0.85
0.80
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00


pred=2, label=2
pred=0, label=0
pred=4, label=4
pred=8, label=8
pred=7, label=7
pred=6, label=6
pred=0, label=0
pred=6, label=6
pred=3, label=3
pred=1, label=1
pred=8, label=8
pred=0, label=0
pred=7, label=7
pred=9, label=9
pred=8, label=8
pred=4, label=4
pred=5, label=5
pred=3, label=3
pred=4, label=4
pred=0, label=0
pred=6, label=6
pred=6, label=6
pred=3, label=3
pred=0, label=0
pred=2, label=2