Introduction

what is a neural network?

A neural Network is a computational model inspired by the human brain. Each neuron recieves an activation signal from the preceeding layer and computes some value that is propoagated forward #### Key Concepts:

- **Input Layer**: Receives the raw input data (e.g., pixel values from an image).
- **Hidden Layers**: Perform computations to extract meaningful features.
- **Output Layer**: Produces the final predictions (e.g., the digit class).

Activation Functions: Activation functions (e.g., ReLU, sigmoid) introduce non-linearity into the model, enabling it to learn complex patterns.

Loss Function: The loss function measures the error between the predicted outputs and the true labels. In this task, we'll use Cross Entropy Loss, which is commonly used for classification problems.

Optimization: The optimizer (e.g., Stochastic Gradient Descent) updates the network's weights to minimize the loss function during training.

Problem Statement: In this assignment, we will use the MNIST dataset to train a neural network to classify handwritten digits (0-9). We'll explore various hyperparameters, analyze their effects, and optionally use advanced techniques such as convolutional layers and dropout.

1 Data Processing

before we attempt to train our model we must make sure that our data conforms with required criteria:

- the samples are tensors
- 60 % training , 20 % validation , 20 % test
- keep a "straigtified" manner to avoid data skewing

```
import torch
import torch.nn as nn
import torch.optim as optim
import matplotlib.pyplot as plt
import seaborn as sns
from sklearn.metrics import confusion_matrix
import numpy as np
import pandas as pd
from torchvision import datasets, transforms
from torch.utils.data import DataLoader,Subset,ConcatDataset
from sklearn.model_selection import train_test_split
from sklearn.metrics import accuracy_score
import numpy as np
```

```
# Apply transformations (convert to tensor and normalize)
transform = transforms.Compose([
    transforms.ToTensor(), #convert vector values in range [0,1]
    transforms.Normalize((0.5,), (0.5,))  # Normalize to [-1, 1] range
(z socre)
])

# Load the MNIST dataset
train_dataset = datasets.MNIST(root='./data', train=True,
transform=transform) #this structure contains data and labels
test_dataset = datasets.MNIST(root='./data', train=False,
transform=transform)

#combine the datasets
combined_dataset=ConcatDataset([train_dataset,test_dataset])

#extract labels
train_labels=train_dataset.targets
test_labels=test_dataset.targets

# Combine labels from both train and test datasets
all_labels = torch.cat((train_labels, test_labels), dim=0)

#split into 60-40
train_idx, temp_idx = train_test_split(
    range(len(combined_dataset)), test_size=0.4, stratify=all_labels,
random_state=42) # stratify 3lshan not to get skewed data


#split again 20-20
# Split temp (40%) into validation (20%) and test (20%)
val_idx, test_idx = train_test_split(
    temp_idx, test_size=0.5, stratify=all_labels[temp_idx],
random_state=42) # returns indices


# Create Subset objects for train, validation, and test sets
train_data = Subset(combined_dataset, train_idx)
val_data = Subset(combined_dataset, val_idx)
test_data = Subset(combined_dataset, test_idx)


##recreate dataset w inheirt combatible structure with data loader
# Create DataLoader objects
batch_size = 32
train_loader = DataLoader(train_data, batch_size=batch_size,
shuffle=True)
val_loader = DataLoader(val_data, batch_size=batch_size,
shuffle=False)
test_loader = DataLoader(test_data, batch_size=batch_size,
```

```
shuffle=False)

# Print split sizes
print(f"Training set size: {len(train_data)}")
print(f"Validation set size: {len(val_data)}")
print(f"Test set size: {len(test_data)}")
print("Data preparation complete!")
```

```
Training set size: 42000
Validation set size: 14000
Test set size: 14000
Data preparation complete!
```

now we build our neural network architecture. we will start with a basic model containing a single hidden layer.

```
# 2 create neural network structure
class Neural_Network_1_hidden_layer(nn.Module):
        def __init__(self, input_size=28*28, hidden_size=10,
num_classes=10):
            super(Neural_Network_1_hidden_layer, self).__init__()
            self.fc1 = nn.Linear(input_size, hidden_size)
            self.fc2 = nn.Linear(hidden_size, num_classes)

        def forward(self, x):
            x = x.view(-1, 28*28)  # Flatten the input
            x = torch.relu(self.fc1(x))  # Apply ReLU activation after
first hidden layer
            x = self.fc2(x)  # Output layer
            return x
```

before we start the training process we need to make sure that we are using GPU accelerated training

```
# 3. Set device to GPU if available, else fallback to CPU
device = torch.device("cuda" if torch.cuda.is_available() else "cpu")

# Instantiate the model and move it to the selected device
model = Neural_Network_1_hidden_layer().to(device)

# Loss function and optimizer
criterion = nn.CrossEntropyLoss() # compud cross entropy with softmax
optimizer = optim.SGD(model.parameters(), lr=0.01)
```

we will now proceed to train our model for 10 epochs where each epoch consists of a training phase followed by a vildation phase.

```
# 4. Training Process
def train_model(model, train_loader, val_loader, criterion, optimizer,
num_epochs=10):
    train_losses, val_losses = [], []
    train_accuracies, val_accuracies = [], []

    for epoch in range(num_epochs):
        model.train()
        running_loss = 0.0 # this is the cumulative loss during epoch
        correct_train = 0
        total_train = 0

        # Train the model on the training set
        for images, labels in train_loader:
            images, labels = images.to(device), labels.to(device)  #
Move to GPU

            optimizer.zero_grad()
            outputs = model(images)  # Forward pass
            loss = criterion(outputs, labels)  # Compute loss
            loss.backward()  # Backward pass (compute gradients)
            optimizer.step()  # Update weights

            running_loss += loss.item()
            _, predicted = torch.max(outputs, 1)  # Get the predicted
class
            correct_train += (predicted == labels).sum().item()
            total_train += labels.size(0)

        avg_train_loss = running_loss / len(train_loader)
        train_accuracy = correct_train / total_train * 100
        train_losses.append(avg_train_loss)
        train_accuracies.append(train_accuracy)

        # Validation phase
        model.eval()
        running_loss = 0.0
        correct_val = 0
        total_val = 0

        with torch.no_grad():
            for images, labels in val_loader:
                images, labels = images.to(device), labels.to(device)
# Move to GPU
                outputs = model(images)  # Forward pass
                loss = criterion(outputs, labels)

                running_loss += loss.item()
                _, predicted = torch.max(outputs, 1)
```

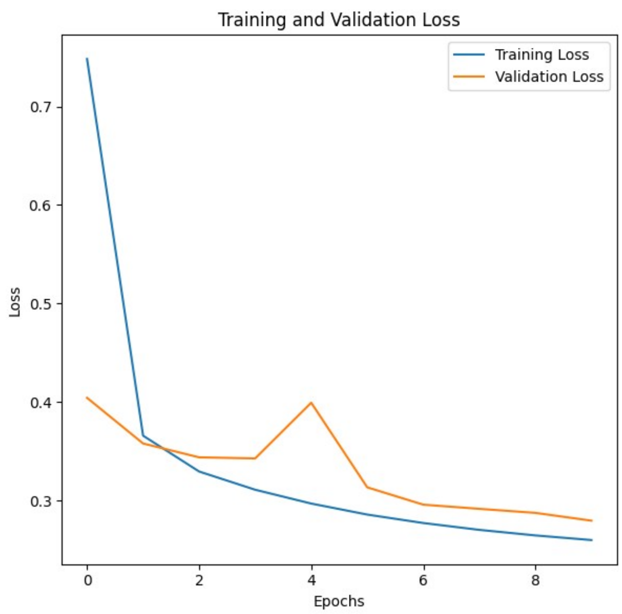
```
                correct_val += (predicted == labels).sum().item()
                total_val += labels.size(0)

        avg_val_loss = running_loss / len(val_loader)
        val_accuracy = correct_val / total_val * 100
        val_losses.append(avg_val_loss)
        val_accuracies.append(val_accuracy)

        print(f"Epoch [{epoch+1}/{num_epochs}], "
              f"Train Loss: {avg_train_loss:.4f}, Train Accuracy: 
{train_accuracy:.2f}%, "
              f"Validation Loss: {avg_val_loss:.4f}, Validation 
Accuracy: {val_accuracy:.2f}%")

    return train_losses, val_losses, train_accuracies, val_accuracies

# Train the model
train_losses, val_losses, train_accuracies, val_accuracies = 
train_model(
    model, train_loader, val_loader, criterion, optimizer, 
num_epochs=10
)
```

```
Epoch [1/10], Train Loss: 0.7482, Train Accuracy: 79.45%, Validation 
Loss: 0.4044, Validation Accuracy: 88.41%
Epoch [2/10], Train Loss: 0.3660, Train Accuracy: 89.56%, Validation 
Loss: 0.3581, Validation Accuracy: 89.84%
Epoch [3/10], Train Loss: 0.3296, Train Accuracy: 90.50%, Validation 
Loss: 0.3440, Validation Accuracy: 90.03%
Epoch [4/10], Train Loss: 0.3111, Train Accuracy: 91.06%, Validation 
Loss: 0.3429, Validation Accuracy: 90.07%
Epoch [5/10], Train Loss: 0.2971, Train Accuracy: 91.52%, Validation 
Loss: 0.3994, Validation Accuracy: 87.59%
Epoch [6/10], Train Loss: 0.2860, Train Accuracy: 91.93%, Validation 
Loss: 0.3136, Validation Accuracy: 90.84%
Epoch [7/10], Train Loss: 0.2774, Train Accuracy: 92.08%, Validation 
Loss: 0.2960, Validation Accuracy: 91.43%
Epoch [8/10], Train Loss: 0.2704, Train Accuracy: 92.21%, Validation 
Loss: 0.2918, Validation Accuracy: 91.71%
Epoch [9/10], Train Loss: 0.2648, Train Accuracy: 92.42%, Validation 
Loss: 0.2877, Validation Accuracy: 91.74%
Epoch [10/10], Train Loss: 0.2601, Train Accuracy: 92.64%, Validation 
Loss: 0.2798, Validation Accuracy: 91.90%
```

now we plot the performance of our simple model

```
# 5. Plot Training and Validation Loss
plt.figure(figsize=(12, 6))
plt.subplot(1, 2, 1)
plt.plot(train_losses, label='Training Loss')
```

```
plt.plot(val_losses, label='Validation Loss')
plt.title('Training and Validation Loss')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.legend()

# 6. Plot Training and Validation Accuracy
plt.subplot(1, 2, 2)
plt.plot(train_accuracies, label='Training Accuracy')
plt.plot(val_accuracies, label='Validation Accuracy')
plt.title('Training and Validation Accuracy')
plt.xlabel('Epochs')
plt.ylabel('Accuracy (%)')
plt.legend()

plt.tight_layout()
plt.show()
```



part 2

for this part we will attempt to tune the model parameters by tweaking a single paramter(the others remain constant) and retraining the model and then comparing results we will use the following paramters:

- number of hiddden layers =[1,3,5,7]
- number of neurons per hidden layer= [10,20,30,40]
- batch size for stochastic gradient descent= [32,64,128,256]
- learning rate =[0.10.01,0.001,0.0001]

in total, we train the model for a total of 16 times.

Total iterations: 6+6+6+6=24

we will create a function the iterates over the said parameters but fristly we define our parameter ranges in a dictionary.

```
# Hyperparameters for tuning
default_params = {
    "hidden_layers": 1,  # Number of hidden layers
    "hidden_size": 10,   # Number of neurons per hidden layer
    "batch_size": 32,    # Batch size for SGD
    "learning_rate": 0.01  # Learning rate
}

# Define the ranges for each hyperparameter
param_ranges = {
    "hidden_layers": [1, 3, 5, 7,9,11],
    "hidden_size": [10, 20, 30, 40, 50 , 60],
    "batch_size": [32, 64, 128, 256,500, 1000 ],
    "learning_rate": [0.1, 0.01, 0.001, 0.0001, 0.00001, 0.000001]
}
```

then we proceed to create a neural network class with a variable layer size

```
def train_model(model, train_loader, val_loader, criterion, optimizer, 
num_epochs=10):
    train_losses, val_losses = [], []
    train_accuracies, val_accuracies = [], []
    y_true, y_pred = [], []

    for epoch in range(num_epochs):
        model.train()
        running_loss = 0.0
        correct_train = 0
        total_train = 0

        for images, labels in train_loader:
            images, labels = images.to(device), labels.to(device)  # 
Move to GPU/CPU
            optimizer.zero_grad() # remove gradients to prevent 
gradient accumulatioin
            outputs = model(images)
            loss = criterion(outputs, labels)
            loss.backward() # calculate gradients
            optimizer.step() #update weights

            running_loss += loss.item() # add current batch loss
            _, predicted = torch.max(outputs, 1) # index of max 
probability
            correct_train += (predicted == labels).sum().item()
            total_train += labels.size(0)# keep track of all samples
```

```
trained

        avg_train_loss = running_loss / len(train_loader)
        train_accuracy = correct_train / total_train * 100
        train_losses.append(avg_train_loss)
        train_accuracies.append(train_accuracy)

        # Validation phase
        model.eval()
        running_loss = 0.0
        correct_val = 0
        total_val = 0
        with torch.no_grad():
            for images, labels in val_loader:
                images, labels = images.to(device), labels.to(device)
                outputs = model(images)
                loss = criterion(outputs, labels)
                running_loss += loss.item()
                _, predicted = torch.max(outputs, 1)
                correct_val += (predicted == labels).sum().item()
                total_val += labels.size(0)
                y_true.extend(labels.cpu().numpy()) ##move to cpu for
transforming into numpy array
                y_pred.extend(predicted.cpu().numpy())

        avg_val_loss = running_loss / len(val_loader)
        val_accuracy = correct_val / total_val * 100
        val_losses.append(avg_val_loss)
        val_accuracies.append(val_accuracy)

        print(f"Epoch [{epoch+1}/{num_epochs}], Train Loss:
{avg_train_loss:.4f}, Train Accuracy: {train_accuracy:.2f}%, "
              f"Validation Loss: {avg_val_loss:.4f}, Validation
Accuracy: {val_accuracy:.2f}%")

    # Return all six variables
    return train_losses, val_losses, train_accuracies, val_accuracies,
y_true, y_pred
```

note that the softmax activation function is not applied directly since the loss criterion is a compound function.

```
# Function to build a model with variable hidden layers
class NeuralNetwork(nn.Module):
    def __init__(self, input_size, hidden_layers, hidden_size,
num_classes):
        super(NeuralNetwork, self).__init__()
        layers = []
        for i in range(hidden_layers):
```

```
            if i == 0:
                layers.append(nn.Linear(input_size, hidden_size)) #
for inout layer
            else:
                layers.append(nn.Linear(hidden_size, hidden_size))
##every layer in between
            layers.append(nn.ReLU())
        layers.append(nn.Linear(hidden_size, num_classes))  # Final
output layer
        self.network = nn.Sequential(*layers) ##link layers

    def forward(self, x):
        x = x.view(-1, 28 * 28)  # Flatten input
        return self.network(x)
```

a function that iterares over parameter values

```
# Hyperparameter tuning function
def tune_hyperparameters(default_params, param_ranges, num_epochs=10):
    results = []

    # Iterate over each parameter
    for param, values in param_ranges.items():
        for value in values:
            # Update the parameter value
            params = default_params.copy()
            params[param] = value

            # Update DataLoader if batch_size changes
            batch_size = params["batch_size"]
            train_loader = DataLoader(train_data,
batch_size=batch_size, shuffle=True)
            val_loader = DataLoader(val_data, batch_size=batch_size,
shuffle=False)

            # Build the model
            model = NeuralNetwork(
                input_size=28 * 28,
                hidden_layers=params["hidden_layers"],
                hidden_size=params["hidden_size"],
                num_classes=10
            ).to(device)

            # Define optimizer with new learning rate
            optimizer = optim.SGD(model.parameters(),
lr=params["learning_rate"])
            criterion = nn.CrossEntropyLoss()

            # Train the model
```

```python
            train_losses, val_losses, train_accuracies,
val_accuracies, y_true, y_pred = train_model(
                model, train_loader, val_loader, criterion, optimizer,
num_epochs=num_epochs
            )

            # Record results
            results.append({
                "param": param,
                "value": value,
                "train_accuracy": train_accuracies[-1],
                "val_accuracy": val_accuracies[-1],
                "train_loss": train_losses[-1],
                "val_loss": val_losses[-1],
                "y_true": y_true,
                "y_pred": y_pred
            })

            print(f"Completed training for {param} = {value}")

    return results

results = tune_hyperparameters(default_params, param_ranges)
```

```
Epoch [1/10], Train Loss: 0.7375, Train Accuracy: 78.66%, Validation
Loss: 0.4049, Validation Accuracy: 88.85%
Epoch [2/10], Train Loss: 0.3615, Train Accuracy: 89.62%, Validation
Loss: 0.3425, Validation Accuracy: 90.00%
Epoch [3/10], Train Loss: 0.3255, Train Accuracy: 90.47%, Validation
Loss: 0.3280, Validation Accuracy: 90.59%
Epoch [4/10], Train Loss: 0.3084, Train Accuracy: 91.12%, Validation
Loss: 0.3418, Validation Accuracy: 90.21%
Epoch [5/10], Train Loss: 0.2994, Train Accuracy: 91.34%, Validation
Loss: 0.3279, Validation Accuracy: 90.37%
Epoch [6/10], Train Loss: 0.2913, Train Accuracy: 91.56%, Validation
Loss: 0.3195, Validation Accuracy: 90.84%
Epoch [7/10], Train Loss: 0.2862, Train Accuracy: 91.77%, Validation
Loss: 0.3006, Validation Accuracy: 91.45%
Epoch [8/10], Train Loss: 0.2806, Train Accuracy: 92.00%, Validation
Loss: 0.3118, Validation Accuracy: 91.15%
Epoch [9/10], Train Loss: 0.2762, Train Accuracy: 92.06%, Validation
Loss: 0.2992, Validation Accuracy: 91.62%
Epoch [10/10], Train Loss: 0.2725, Train Accuracy: 92.13%, Validation
Loss: 0.3069, Validation Accuracy: 91.14%
Completed training for hidden_layers = 1
Epoch [1/10], Train Loss: 1.5809, Train Accuracy: 42.68%, Validation
Loss: 0.8274, Validation Accuracy: 71.73%
Epoch [2/10], Train Loss: 0.6531, Train Accuracy: 78.79%, Validation
Loss: 0.5995, Validation Accuracy: 80.88%
Epoch [3/10], Train Loss: 0.5063, Train Accuracy: 84.48%, Validation
```

```
Loss: 0.5137, Validation Accuracy: 83.95%
Epoch [4/10], Train Loss: 0.4301, Train Accuracy: 87.00%, Validation
Loss: 0.4086, Validation Accuracy: 87.99%
Epoch [5/10], Train Loss: 0.3751, Train Accuracy: 88.84%, Validation
Loss: 0.4090, Validation Accuracy: 87.93%
Epoch [6/10], Train Loss: 0.3418, Train Accuracy: 90.00%, Validation
Loss: 0.3557, Validation Accuracy: 89.86%
Epoch [7/10], Train Loss: 0.3157, Train Accuracy: 90.79%, Validation
Loss: 0.3233, Validation Accuracy: 90.57%
Epoch [8/10], Train Loss: 0.2968, Train Accuracy: 91.26%, Validation
Loss: 0.3579, Validation Accuracy: 89.38%
Epoch [9/10], Train Loss: 0.2832, Train Accuracy: 91.72%, Validation
Loss: 0.2979, Validation Accuracy: 91.59%
Epoch [10/10], Train Loss: 0.2712, Train Accuracy: 92.02%, Validation
Loss: 0.3433, Validation Accuracy: 89.72%
Completed training for hidden_layers = 3
Epoch [1/10], Train Loss: 2.2908, Train Accuracy: 12.75%, Validation
Loss: 2.2298, Validation Accuracy: 18.09%
Epoch [2/10], Train Loss: 1.9531, Train Accuracy: 22.17%, Validation
Loss: 1.7552, Validation Accuracy: 27.11%
Epoch [3/10], Train Loss: 1.5279, Train Accuracy: 40.68%, Validation
Loss: 1.3227, Validation Accuracy: 52.06%
Epoch [4/10], Train Loss: 1.1080, Train Accuracy: 61.25%, Validation
Loss: 0.7788, Validation Accuracy: 75.16%
Epoch [5/10], Train Loss: 0.6799, Train Accuracy: 79.25%, Validation
Loss: 0.5745, Validation Accuracy: 83.99%
Epoch [6/10], Train Loss: 0.5219, Train Accuracy: 84.90%, Validation
Loss: 0.4639, Validation Accuracy: 86.96%
Epoch [7/10], Train Loss: 0.4530, Train Accuracy: 86.78%, Validation
Loss: 0.4664, Validation Accuracy: 86.40%
Epoch [8/10], Train Loss: 0.4098, Train Accuracy: 88.05%, Validation
Loss: 0.4443, Validation Accuracy: 87.19%
Epoch [9/10], Train Loss: 0.3797, Train Accuracy: 88.95%, Validation
Loss: 0.4168, Validation Accuracy: 87.31%
Epoch [10/10], Train Loss: 0.3539, Train Accuracy: 89.63%, Validation
Loss: 0.3976, Validation Accuracy: 88.86%
Completed training for hidden_layers = 5
Epoch [1/10], Train Loss: 2.3053, Train Accuracy: 10.67%, Validation
Loss: 2.3017, Validation Accuracy: 11.26%
Epoch [2/10], Train Loss: 2.3014, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [3/10], Train Loss: 2.3012, Train Accuracy: 11.25%, Validation
Loss: 2.3010, Validation Accuracy: 11.26%
Epoch [4/10], Train Loss: 2.3012, Train Accuracy: 11.25%, Validation
Loss: 2.3009, Validation Accuracy: 11.26%
Epoch [5/10], Train Loss: 2.3011, Train Accuracy: 11.25%, Validation
Loss: 2.3008, Validation Accuracy: 11.26%
Epoch [6/10], Train Loss: 2.3008, Train Accuracy: 11.25%, Validation
Loss: 2.3005, Validation Accuracy: 11.26%
```

```
Epoch [7/10], Train Loss: 2.3001, Train Accuracy: 11.25%, Validation
Loss: 2.2989, Validation Accuracy: 11.26%
Epoch [8/10], Train Loss: 2.2944, Train Accuracy: 11.25%, Validation
Loss: 2.2821, Validation Accuracy: 11.26%
Epoch [9/10], Train Loss: 2.1158, Train Accuracy: 20.66%, Validation
Loss: 1.8593, Validation Accuracy: 19.96%
Epoch [10/10], Train Loss: 1.7073, Train Accuracy: 27.73%, Validation
Loss: 1.5794, Validation Accuracy: 34.14%
Completed training for hidden_layers = 7
Epoch [1/10], Train Loss: 2.3041, Train Accuracy: 10.35%, Validation
Loss: 2.3014, Validation Accuracy: 11.26%
Epoch [2/10], Train Loss: 2.3014, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [3/10], Train Loss: 2.3013, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [4/10], Train Loss: 2.3013, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [5/10], Train Loss: 2.3013, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [6/10], Train Loss: 2.3013, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [7/10], Train Loss: 2.3012, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [8/10], Train Loss: 2.3012, Train Accuracy: 11.25%, Validation
Loss: 2.3010, Validation Accuracy: 11.26%
Epoch [9/10], Train Loss: 2.3012, Train Accuracy: 11.25%, Validation
Loss: 2.3010, Validation Accuracy: 11.26%
Epoch [10/10], Train Loss: 2.3011, Train Accuracy: 11.25%, Validation
Loss: 2.3009, Validation Accuracy: 11.26%
Completed training for hidden_layers = 9
Epoch [1/10], Train Loss: 2.3072, Train Accuracy: 9.87%, Validation
Loss: 2.3017, Validation Accuracy: 11.26%
Epoch [2/10], Train Loss: 2.3015, Train Accuracy: 11.24%, Validation
Loss: 2.3012, Validation Accuracy: 11.26%
Epoch [3/10], Train Loss: 2.3013, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [4/10], Train Loss: 2.3013, Train Accuracy: 11.25%, Validation
Loss: 2.3012, Validation Accuracy: 11.26%
Epoch [5/10], Train Loss: 2.3013, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [6/10], Train Loss: 2.3013, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [7/10], Train Loss: 2.3013, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [8/10], Train Loss: 2.3013, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [9/10], Train Loss: 2.3013, Train Accuracy: 11.25%, Validation
Loss: 2.3011, Validation Accuracy: 11.26%
Epoch [10/10], Train Loss: 2.3013, Train Accuracy: 11.25%, Validation
```

```
Loss: 2.3011, Validation Accuracy: 11.26%
Completed training for hidden_layers = 11
Epoch [1/10], Train Loss: 0.7830, Train Accuracy: 78.27%, Validation
Loss: 0.4372, Validation Accuracy: 87.58%
Epoch [2/10], Train Loss: 0.3814, Train Accuracy: 88.90%, Validation
Loss: 0.3614, Validation Accuracy: 89.36%
Epoch [3/10], Train Loss: 0.3350, Train Accuracy: 90.36%, Validation
Loss: 0.3475, Validation Accuracy: 89.90%
Epoch [4/10], Train Loss: 0.3115, Train Accuracy: 91.08%, Validation
Loss: 0.3231, Validation Accuracy: 90.75%
Epoch [5/10], Train Loss: 0.2961, Train Accuracy: 91.46%, Validation
Loss: 0.3086, Validation Accuracy: 90.92%
Epoch [6/10], Train Loss: 0.2833, Train Accuracy: 91.88%, Validation
Loss: 0.2998, Validation Accuracy: 91.51%
Epoch [7/10], Train Loss: 0.2751, Train Accuracy: 92.00%, Validation
Loss: 0.3017, Validation Accuracy: 91.36%
Epoch [8/10], Train Loss: 0.2667, Train Accuracy: 92.17%, Validation
Loss: 0.2924, Validation Accuracy: 91.62%
Epoch [9/10], Train Loss: 0.2601, Train Accuracy: 92.45%, Validation
Loss: 0.2847, Validation Accuracy: 91.79%
Epoch [10/10], Train Loss: 0.2547, Train Accuracy: 92.53%, Validation
Loss: 0.3030, Validation Accuracy: 91.38%
Completed training for hidden_size = 10
Epoch [1/10], Train Loss: 0.7059, Train Accuracy: 80.71%, Validation
Loss: 0.3968, Validation Accuracy: 88.72%
Epoch [2/10], Train Loss: 0.3519, Train Accuracy: 89.83%, Validation
Loss: 0.3286, Validation Accuracy: 90.76%
Epoch [3/10], Train Loss: 0.3127, Train Accuracy: 91.00%, Validation
Loss: 0.3088, Validation Accuracy: 91.26%
Epoch [4/10], Train Loss: 0.2883, Train Accuracy: 91.61%, Validation
Loss: 0.2931, Validation Accuracy: 91.43%
Epoch [5/10], Train Loss: 0.2701, Train Accuracy: 92.24%, Validation
Loss: 0.2775, Validation Accuracy: 91.84%
Epoch [6/10], Train Loss: 0.2552, Train Accuracy: 92.68%, Validation
Loss: 0.2724, Validation Accuracy: 91.91%
Epoch [7/10], Train Loss: 0.2423, Train Accuracy: 92.93%, Validation
Loss: 0.2627, Validation Accuracy: 92.46%
Epoch [8/10], Train Loss: 0.2322, Train Accuracy: 93.30%, Validation
Loss: 0.2504, Validation Accuracy: 92.81%
Epoch [9/10], Train Loss: 0.2232, Train Accuracy: 93.59%, Validation
Loss: 0.2501, Validation Accuracy: 92.60%
Epoch [10/10], Train Loss: 0.2144, Train Accuracy: 93.77%, Validation
Loss: 0.2382, Validation Accuracy: 93.11%
Completed training for hidden_size = 20
Epoch [1/10], Train Loss: 0.6799, Train Accuracy: 82.15%, Validation
Loss: 0.3854, Validation Accuracy: 88.96%
Epoch [2/10], Train Loss: 0.3493, Train Accuracy: 90.03%, Validation
Loss: 0.3376, Validation Accuracy: 90.21%
Epoch [3/10], Train Loss: 0.3111, Train Accuracy: 91.03%, Validation
```

```
Loss: 0.3203, Validation Accuracy: 90.54%
Epoch [4/10], Train Loss: 0.2878, Train Accuracy: 91.74%, Validation
Loss: 0.2998, Validation Accuracy: 91.16%
Epoch [5/10], Train Loss: 0.2682, Train Accuracy: 92.25%, Validation
Loss: 0.2777, Validation Accuracy: 92.16%
Epoch [6/10], Train Loss: 0.2502, Train Accuracy: 92.82%, Validation
Loss: 0.2590, Validation Accuracy: 92.55%
Epoch [7/10], Train Loss: 0.2344, Train Accuracy: 93.33%, Validation
Loss: 0.2470, Validation Accuracy: 92.89%
Epoch [8/10], Train Loss: 0.2208, Train Accuracy: 93.64%, Validation
Loss: 0.2356, Validation Accuracy: 93.29%
Epoch [9/10], Train Loss: 0.2086, Train Accuracy: 94.15%, Validation
Loss: 0.2260, Validation Accuracy: 93.57%
Epoch [10/10], Train Loss: 0.1964, Train Accuracy: 94.40%, Validation
Loss: 0.2206, Validation Accuracy: 93.71%
Completed training for hidden_size = 30
Epoch [1/10], Train Loss: 0.6885, Train Accuracy: 82.46%, Validation
Loss: 0.3941, Validation Accuracy: 88.69%
Epoch [2/10], Train Loss: 0.3496, Train Accuracy: 89.99%, Validation
Loss: 0.3416, Validation Accuracy: 90.18%
Epoch [3/10], Train Loss: 0.3084, Train Accuracy: 91.11%, Validation
Loss: 0.3089, Validation Accuracy: 90.86%
Epoch [4/10], Train Loss: 0.2814, Train Accuracy: 91.87%, Validation
Loss: 0.2868, Validation Accuracy: 91.72%
Epoch [5/10], Train Loss: 0.2602, Train Accuracy: 92.56%, Validation
Loss: 0.2625, Validation Accuracy: 92.36%
Epoch [6/10], Train Loss: 0.2416, Train Accuracy: 93.03%, Validation
Loss: 0.2529, Validation Accuracy: 92.66%
Epoch [7/10], Train Loss: 0.2254, Train Accuracy: 93.51%, Validation
Loss: 0.2498, Validation Accuracy: 92.72%
Epoch [8/10], Train Loss: 0.2101, Train Accuracy: 94.01%, Validation
Loss: 0.2252, Validation Accuracy: 93.63%
Epoch [9/10], Train Loss: 0.1983, Train Accuracy: 94.37%, Validation
Loss: 0.2128, Validation Accuracy: 93.86%
Epoch [10/10], Train Loss: 0.1865, Train Accuracy: 94.65%, Validation
Loss: 0.2021, Validation Accuracy: 94.09%
Completed training for hidden_size = 40
Epoch [1/10], Train Loss: 0.6572, Train Accuracy: 82.99%, Validation
Loss: 0.3835, Validation Accuracy: 88.89%
Epoch [2/10], Train Loss: 0.3438, Train Accuracy: 90.05%, Validation
Loss: 0.3367, Validation Accuracy: 90.19%
Epoch [3/10], Train Loss: 0.3032, Train Accuracy: 91.23%, Validation
Loss: 0.3024, Validation Accuracy: 91.25%
Epoch [4/10], Train Loss: 0.2780, Train Accuracy: 91.93%, Validation
Loss: 0.2769, Validation Accuracy: 92.14%
Epoch [5/10], Train Loss: 0.2553, Train Accuracy: 92.55%, Validation
Loss: 0.2700, Validation Accuracy: 92.50%
Epoch [6/10], Train Loss: 0.2352, Train Accuracy: 93.25%, Validation
Loss: 0.2536, Validation Accuracy: 92.51%
```

```
Epoch [7/10], Train Loss: 0.2173, Train Accuracy: 93.80%, Validation
Loss: 0.2385, Validation Accuracy: 92.94%
Epoch [8/10], Train Loss: 0.2018, Train Accuracy: 94.24%, Validation
Loss: 0.2156, Validation Accuracy: 93.89%
Epoch [9/10], Train Loss: 0.1879, Train Accuracy: 94.61%, Validation
Loss: 0.2070, Validation Accuracy: 94.03%
Epoch [10/10], Train Loss: 0.1769, Train Accuracy: 95.01%, Validation
Loss: 0.1980, Validation Accuracy: 94.24%
Completed training for hidden_size = 50
Epoch [1/10], Train Loss: 0.6829, Train Accuracy: 82.25%, Validation
Loss: 0.3841, Validation Accuracy: 88.79%
Epoch [2/10], Train Loss: 0.3431, Train Accuracy: 90.19%, Validation
Loss: 0.3386, Validation Accuracy: 90.34%
Epoch [3/10], Train Loss: 0.3021, Train Accuracy: 91.25%, Validation
Loss: 0.3040, Validation Accuracy: 91.05%
Epoch [4/10], Train Loss: 0.2758, Train Accuracy: 92.11%, Validation
Loss: 0.2752, Validation Accuracy: 92.09%
Epoch [5/10], Train Loss: 0.2533, Train Accuracy: 92.73%, Validation
Loss: 0.2658, Validation Accuracy: 92.51%
Epoch [6/10], Train Loss: 0.2325, Train Accuracy: 93.41%, Validation
Loss: 0.2407, Validation Accuracy: 93.09%
Epoch [7/10], Train Loss: 0.2145, Train Accuracy: 94.00%, Validation
Loss: 0.2284, Validation Accuracy: 93.46%
Epoch [8/10], Train Loss: 0.1979, Train Accuracy: 94.40%, Validation
Loss: 0.2102, Validation Accuracy: 93.95%
Epoch [9/10], Train Loss: 0.1841, Train Accuracy: 94.73%, Validation
Loss: 0.1988, Validation Accuracy: 94.21%
Epoch [10/10], Train Loss: 0.1720, Train Accuracy: 95.11%, Validation
Loss: 0.2025, Validation Accuracy: 94.11%
Completed training for hidden_size = 60
Epoch [1/10], Train Loss: 0.7847, Train Accuracy: 76.92%, Validation
Loss: 0.4333, Validation Accuracy: 87.92%
Epoch [2/10], Train Loss: 0.3829, Train Accuracy: 88.84%, Validation
Loss: 0.4063, Validation Accuracy: 87.79%
Epoch [3/10], Train Loss: 0.3382, Train Accuracy: 90.24%, Validation
Loss: 0.3421, Validation Accuracy: 90.31%
Epoch [4/10], Train Loss: 0.3161, Train Accuracy: 90.88%, Validation
Loss: 0.3267, Validation Accuracy: 90.89%
Epoch [5/10], Train Loss: 0.3025, Train Accuracy: 91.31%, Validation
Loss: 0.3163, Validation Accuracy: 91.11%
Epoch [6/10], Train Loss: 0.2929, Train Accuracy: 91.50%, Validation
Loss: 0.3152, Validation Accuracy: 90.98%
Epoch [7/10], Train Loss: 0.2848, Train Accuracy: 91.84%, Validation
Loss: 0.3048, Validation Accuracy: 91.55%
Epoch [8/10], Train Loss: 0.2789, Train Accuracy: 91.95%, Validation
Loss: 0.3034, Validation Accuracy: 91.28%
Epoch [9/10], Train Loss: 0.2726, Train Accuracy: 92.27%, Validation
Loss: 0.2915, Validation Accuracy: 91.90%
Epoch [10/10], Train Loss: 0.2675, Train Accuracy: 92.31%, Validation
```

```
Loss: 0.2954, Validation Accuracy: 91.54%
Completed training for batch_size = 32
Epoch [1/10], Train Loss: 1.1709, Train Accuracy: 67.06%, Validation
Loss: 0.5740, Validation Accuracy: 84.07%
Epoch [2/10], Train Loss: 0.4599, Train Accuracy: 87.05%, Validation
Loss: 0.4144, Validation Accuracy: 88.34%
Epoch [3/10], Train Loss: 0.3769, Train Accuracy: 89.15%, Validation
Loss: 0.3688, Validation Accuracy: 89.34%
Epoch [4/10], Train Loss: 0.3460, Train Accuracy: 89.94%, Validation
Loss: 0.3608, Validation Accuracy: 89.37%
Epoch [5/10], Train Loss: 0.3289, Train Accuracy: 90.49%, Validation
Loss: 0.3336, Validation Accuracy: 90.36%
Epoch [6/10], Train Loss: 0.3163, Train Accuracy: 90.89%, Validation
Loss: 0.3378, Validation Accuracy: 89.97%
Epoch [7/10], Train Loss: 0.3064, Train Accuracy: 91.24%, Validation
Loss: 0.3227, Validation Accuracy: 90.85%
Epoch [8/10], Train Loss: 0.2994, Train Accuracy: 91.45%, Validation
Loss: 0.3245, Validation Accuracy: 90.83%
Epoch [9/10], Train Loss: 0.2937, Train Accuracy: 91.55%, Validation
Loss: 0.3337, Validation Accuracy: 90.08%
Epoch [10/10], Train Loss: 0.2875, Train Accuracy: 91.75%, Validation
Loss: 0.3057, Validation Accuracy: 91.14%
Completed training for batch_size = 64
Epoch [1/10], Train Loss: 1.4954, Train Accuracy: 58.78%, Validation
Loss: 0.8367, Validation Accuracy: 79.84%
Epoch [2/10], Train Loss: 0.6464, Train Accuracy: 83.33%, Validation
Loss: 0.5574, Validation Accuracy: 83.61%
Epoch [3/10], Train Loss: 0.4971, Train Accuracy: 86.19%, Validation
Loss: 0.4764, Validation Accuracy: 86.91%
Epoch [4/10], Train Loss: 0.4369, Train Accuracy: 87.69%, Validation
Loss: 0.4433, Validation Accuracy: 86.88%
Epoch [5/10], Train Loss: 0.4001, Train Accuracy: 88.70%, Validation
Loss: 0.4108, Validation Accuracy: 88.36%
Epoch [6/10], Train Loss: 0.3760, Train Accuracy: 89.44%, Validation
Loss: 0.3803, Validation Accuracy: 89.29%
Epoch [7/10], Train Loss: 0.3600, Train Accuracy: 89.80%, Validation
Loss: 0.3711, Validation Accuracy: 89.24%
Epoch [8/10], Train Loss: 0.3477, Train Accuracy: 90.14%, Validation
Loss: 0.3587, Validation Accuracy: 89.96%
Epoch [9/10], Train Loss: 0.3385, Train Accuracy: 90.42%, Validation
Loss: 0.3625, Validation Accuracy: 89.80%
Epoch [10/10], Train Loss: 0.3321, Train Accuracy: 90.58%, Validation
Loss: 0.3496, Validation Accuracy: 90.22%
Completed training for batch_size = 128
Epoch [1/10], Train Loss: 1.7533, Train Accuracy: 45.45%, Validation
Loss: 1.2389, Validation Accuracy: 67.31%
Epoch [2/10], Train Loss: 0.9887, Train Accuracy: 74.61%, Validation
Loss: 0.8346, Validation Accuracy: 78.26%
Epoch [3/10], Train Loss: 0.7366, Train Accuracy: 80.67%, Validation
```

```
Loss: 0.6726, Validation Accuracy: 81.87%
Epoch [4/10], Train Loss: 0.6124, Train Accuracy: 83.59%, Validation
Loss: 0.5793, Validation Accuracy: 84.37%
Epoch [5/10], Train Loss: 0.5442, Train Accuracy: 85.01%, Validation
Loss: 0.5370, Validation Accuracy: 85.05%
Epoch [6/10], Train Loss: 0.4978, Train Accuracy: 86.12%, Validation
Loss: 0.4957, Validation Accuracy: 86.00%
Epoch [7/10], Train Loss: 0.4649, Train Accuracy: 86.94%, Validation
Loss: 0.4705, Validation Accuracy: 87.06%
Epoch [8/10], Train Loss: 0.4405, Train Accuracy: 87.57%, Validation
Loss: 0.4435, Validation Accuracy: 87.66%
Epoch [9/10], Train Loss: 0.4230, Train Accuracy: 88.06%, Validation
Loss: 0.4312, Validation Accuracy: 87.79%
Epoch [10/10], Train Loss: 0.4100, Train Accuracy: 88.40%, Validation
Loss: 0.4349, Validation Accuracy: 87.54%
Completed training for batch_size = 256
Epoch [1/10], Train Loss: 2.0104, Train Accuracy: 36.34%, Validation
Loss: 1.7546, Validation Accuracy: 47.26%
Epoch [2/10], Train Loss: 1.5353, Train Accuracy: 57.02%, Validation
Loss: 1.3201, Validation Accuracy: 65.65%
Epoch [3/10], Train Loss: 1.1488, Train Accuracy: 71.29%, Validation
Loss: 1.0060, Validation Accuracy: 75.84%
Epoch [4/10], Train Loss: 0.8987, Train Accuracy: 78.14%, Validation
Loss: 0.8126, Validation Accuracy: 79.60%
Epoch [5/10], Train Loss: 0.7432, Train Accuracy: 81.49%, Validation
Loss: 0.6907, Validation Accuracy: 82.15%
Epoch [6/10], Train Loss: 0.6437, Train Accuracy: 83.61%, Validation
Loss: 0.6108, Validation Accuracy: 84.04%
Epoch [7/10], Train Loss: 0.5766, Train Accuracy: 85.04%, Validation
Loss: 0.5552, Validation Accuracy: 85.52%
Epoch [8/10], Train Loss: 0.5291, Train Accuracy: 85.99%, Validation
Loss: 0.5152, Validation Accuracy: 86.49%
Epoch [9/10], Train Loss: 0.4948, Train Accuracy: 86.76%, Validation
Loss: 0.4860, Validation Accuracy: 87.16%
Epoch [10/10], Train Loss: 0.4686, Train Accuracy: 87.32%, Validation
Loss: 0.4640, Validation Accuracy: 87.65%
Completed training for batch_size = 500
Epoch [1/10], Train Loss: 2.2332, Train Accuracy: 24.44%, Validation
Loss: 2.1368, Validation Accuracy: 31.89%
Epoch [2/10], Train Loss: 2.0512, Train Accuracy: 38.74%, Validation
Loss: 1.9639, Validation Accuracy: 44.25%
Epoch [3/10], Train Loss: 1.8703, Train Accuracy: 47.13%, Validation
Loss: 1.7719, Validation Accuracy: 49.64%
Epoch [4/10], Train Loss: 1.6690, Train Accuracy: 51.03%, Validation
Loss: 1.5720, Validation Accuracy: 52.77%
Epoch [5/10], Train Loss: 1.4785, Train Accuracy: 55.17%, Validation
Loss: 1.3959, Validation Accuracy: 58.09%
Epoch [6/10], Train Loss: 1.3185, Train Accuracy: 59.60%, Validation
Loss: 1.2530, Validation Accuracy: 61.51%
```

```
Epoch [7/10], Train Loss: 1.1886, Train Accuracy: 63.81%, Validation
Loss: 1.1346, Validation Accuracy: 65.31%
Epoch [8/10], Train Loss: 1.0761, Train Accuracy: 68.00%, Validation
Loss: 1.0273, Validation Accuracy: 70.03%
Epoch [9/10], Train Loss: 0.9769, Train Accuracy: 72.28%, Validation
Loss: 0.9377, Validation Accuracy: 74.06%
Epoch [10/10], Train Loss: 0.8952, Train Accuracy: 75.59%, Validation
Loss: 0.8636, Validation Accuracy: 76.41%
Completed training for batch_size = 1000
Epoch [1/10], Train Loss: 1.5825, Train Accuracy: 40.59%, Validation
Loss: 1.5127, Validation Accuracy: 43.09%
Epoch [2/10], Train Loss: 1.4450, Train Accuracy: 47.60%, Validation
Loss: 1.9999, Validation Accuracy: 30.75%
Epoch [3/10], Train Loss: 1.4132, Train Accuracy: 49.45%, Validation
Loss: 1.4774, Validation Accuracy: 45.89%
Epoch [4/10], Train Loss: 1.4174, Train Accuracy: 49.92%, Validation
Loss: 1.2822, Validation Accuracy: 52.94%
Epoch [5/10], Train Loss: 1.3994, Train Accuracy: 50.66%, Validation
Loss: 1.2698, Validation Accuracy: 55.84%
Epoch [6/10], Train Loss: 1.3902, Train Accuracy: 51.32%, Validation
Loss: 1.4865, Validation Accuracy: 46.70%
Epoch [7/10], Train Loss: 1.3996, Train Accuracy: 51.24%, Validation
Loss: 1.3105, Validation Accuracy: 52.69%
Epoch [8/10], Train Loss: 1.3798, Train Accuracy: 52.22%, Validation
Loss: 1.5280, Validation Accuracy: 42.46%
Epoch [9/10], Train Loss: 1.3959, Train Accuracy: 51.45%, Validation
Loss: 1.5854, Validation Accuracy: 48.56%
Epoch [10/10], Train Loss: 1.3954, Train Accuracy: 51.31%, Validation
Loss: 1.4562, Validation Accuracy: 52.24%
Completed training for learning_rate = 0.1
Epoch [1/10], Train Loss: 0.7632, Train Accuracy: 77.65%, Validation
Loss: 0.4697, Validation Accuracy: 87.01%
Epoch [2/10], Train Loss: 0.4062, Train Accuracy: 88.29%, Validation
Loss: 0.3892, Validation Accuracy: 89.02%
Epoch [3/10], Train Loss: 0.3493, Train Accuracy: 89.98%, Validation
Loss: 0.3756, Validation Accuracy: 88.93%
Epoch [4/10], Train Loss: 0.3238, Train Accuracy: 90.80%, Validation
Loss: 0.3406, Validation Accuracy: 90.23%
Epoch [5/10], Train Loss: 0.3091, Train Accuracy: 91.28%, Validation
Loss: 0.3290, Validation Accuracy: 90.48%
Epoch [6/10], Train Loss: 0.2981, Train Accuracy: 91.58%, Validation
Loss: 0.3862, Validation Accuracy: 88.66%
Epoch [7/10], Train Loss: 0.2910, Train Accuracy: 91.76%, Validation
Loss: 0.3117, Validation Accuracy: 91.05%
Epoch [8/10], Train Loss: 0.2847, Train Accuracy: 91.97%, Validation
Loss: 0.3117, Validation Accuracy: 91.19%
Epoch [9/10], Train Loss: 0.2781, Train Accuracy: 92.16%, Validation
Loss: 0.3039, Validation Accuracy: 91.27%
Epoch [10/10], Train Loss: 0.2725, Train Accuracy: 92.25%, Validation
```

```
Loss: 0.2952, Validation Accuracy: 91.54%
Completed training for learning_rate = 0.01
Epoch [1/10], Train Loss: 1.9715, Train Accuracy: 34.96%, Validation
Loss: 1.6808, Validation Accuracy: 49.49%
Epoch [2/10], Train Loss: 1.4039, Train Accuracy: 63.21%, Validation
Loss: 1.1364, Validation Accuracy: 73.24%
Epoch [3/10], Train Loss: 0.9567, Train Accuracy: 76.05%, Validation
Loss: 0.8264, Validation Accuracy: 78.46%
Epoch [4/10], Train Loss: 0.7429, Train Accuracy: 79.79%, Validation
Loss: 0.6832, Validation Accuracy: 81.44%
Epoch [5/10], Train Loss: 0.6359, Train Accuracy: 82.38%, Validation
Loss: 0.6021, Validation Accuracy: 83.33%
Epoch [6/10], Train Loss: 0.5704, Train Accuracy: 84.10%, Validation
Loss: 0.5497, Validation Accuracy: 84.59%
Epoch [7/10], Train Loss: 0.5250, Train Accuracy: 85.22%, Validation
Loss: 0.5108, Validation Accuracy: 85.81%
Epoch [8/10], Train Loss: 0.4912, Train Accuracy: 86.13%, Validation
Loss: 0.4818, Validation Accuracy: 86.36%
Epoch [9/10], Train Loss: 0.4646, Train Accuracy: 86.78%, Validation
Loss: 0.4590, Validation Accuracy: 87.15%
Epoch [10/10], Train Loss: 0.4436, Train Accuracy: 87.44%, Validation
Loss: 0.4409, Validation Accuracy: 87.44%
Completed training for learning_rate = 0.001
Epoch [1/10], Train Loss: 2.2552, Train Accuracy: 18.57%, Validation
Loss: 2.1967, Validation Accuracy: 27.56%
Epoch [2/10], Train Loss: 2.1459, Train Accuracy: 34.03%, Validation
Loss: 2.0996, Validation Accuracy: 38.24%
Epoch [3/10], Train Loss: 2.0518, Train Accuracy: 41.58%, Validation
Loss: 2.0044, Validation Accuracy: 45.31%
Epoch [4/10], Train Loss: 1.9575, Train Accuracy: 48.05%, Validation
Loss: 1.9144, Validation Accuracy: 50.22%
Epoch [5/10], Train Loss: 1.8720, Train Accuracy: 51.59%, Validation
Loss: 1.8331, Validation Accuracy: 52.94%
Epoch [6/10], Train Loss: 1.7941, Train Accuracy: 53.77%, Validation
Loss: 1.7588, Validation Accuracy: 55.06%
Epoch [7/10], Train Loss: 1.7226, Train Accuracy: 55.56%, Validation
Loss: 1.6901, Validation Accuracy: 56.54%
Epoch [8/10], Train Loss: 1.6560, Train Accuracy: 57.13%, Validation
Loss: 1.6256, Validation Accuracy: 57.64%
Epoch [9/10], Train Loss: 1.5934, Train Accuracy: 58.37%, Validation
Loss: 1.5648, Validation Accuracy: 59.46%
Epoch [10/10], Train Loss: 1.5339, Train Accuracy: 59.72%, Validation
Loss: 1.5063, Validation Accuracy: 60.79%
Completed training for learning_rate = 0.0001
Epoch [1/10], Train Loss: 2.3281, Train Accuracy: 11.28%, Validation
Loss: 2.3236, Validation Accuracy: 11.39%
Epoch [2/10], Train Loss: 2.3212, Train Accuracy: 11.64%, Validation
Loss: 2.3187, Validation Accuracy: 11.56%
Epoch [3/10], Train Loss: 2.3173, Train Accuracy: 11.78%, Validation
```

```
Loss: 2.3158, Validation Accuracy: 11.59%
Epoch [4/10], Train Loss: 2.3150, Train Accuracy: 11.83%, Validation
Loss: 2.3139, Validation Accuracy: 11.59%
Epoch [5/10], Train Loss: 2.3133, Train Accuracy: 11.85%, Validation
Loss: 2.3125, Validation Accuracy: 11.63%
Epoch [6/10], Train Loss: 2.3119, Train Accuracy: 11.86%, Validation
Loss: 2.3113, Validation Accuracy: 11.68%
Epoch [7/10], Train Loss: 2.3107, Train Accuracy: 11.94%, Validation
Loss: 2.3101, Validation Accuracy: 11.70%
Epoch [8/10], Train Loss: 2.3095, Train Accuracy: 11.95%, Validation
Loss: 2.3090, Validation Accuracy: 11.76%
Epoch [9/10], Train Loss: 2.3084, Train Accuracy: 11.97%, Validation
Loss: 2.3079, Validation Accuracy: 11.76%
Epoch [10/10], Train Loss: 2.3072, Train Accuracy: 12.06%, Validation
Loss: 2.3067, Validation Accuracy: 11.84%
Completed training for learning_rate = 1e-05
Epoch [1/10], Train Loss: 2.3287, Train Accuracy: 10.54%, Validation
Loss: 2.3273, Validation Accuracy: 10.68%
Epoch [2/10], Train Loss: 2.3270, Train Accuracy: 10.52%, Validation
Loss: 2.3256, Validation Accuracy: 10.72%
Epoch [3/10], Train Loss: 2.3253, Train Accuracy: 10.48%, Validation
Loss: 2.3239, Validation Accuracy: 10.61%
Epoch [4/10], Train Loss: 2.3237, Train Accuracy: 10.46%, Validation
Loss: 2.3224, Validation Accuracy: 10.56%
Epoch [5/10], Train Loss: 2.3221, Train Accuracy: 10.39%, Validation
Loss: 2.3208, Validation Accuracy: 10.51%
Epoch [6/10], Train Loss: 2.3206, Train Accuracy: 10.35%, Validation
Loss: 2.3194, Validation Accuracy: 10.49%
Epoch [7/10], Train Loss: 2.3191, Train Accuracy: 10.30%, Validation
Loss: 2.3179, Validation Accuracy: 10.44%
Epoch [8/10], Train Loss: 2.3177, Train Accuracy: 10.23%, Validation
Loss: 2.3165, Validation Accuracy: 10.41%
Epoch [9/10], Train Loss: 2.3163, Train Accuracy: 10.20%, Validation
Loss: 2.3152, Validation Accuracy: 10.36%
Epoch [10/10], Train Loss: 2.3150, Train Accuracy: 10.18%, Validation
Loss: 2.3138, Validation Accuracy: 10.32%
Completed training for learning_rate = 1e-06
```

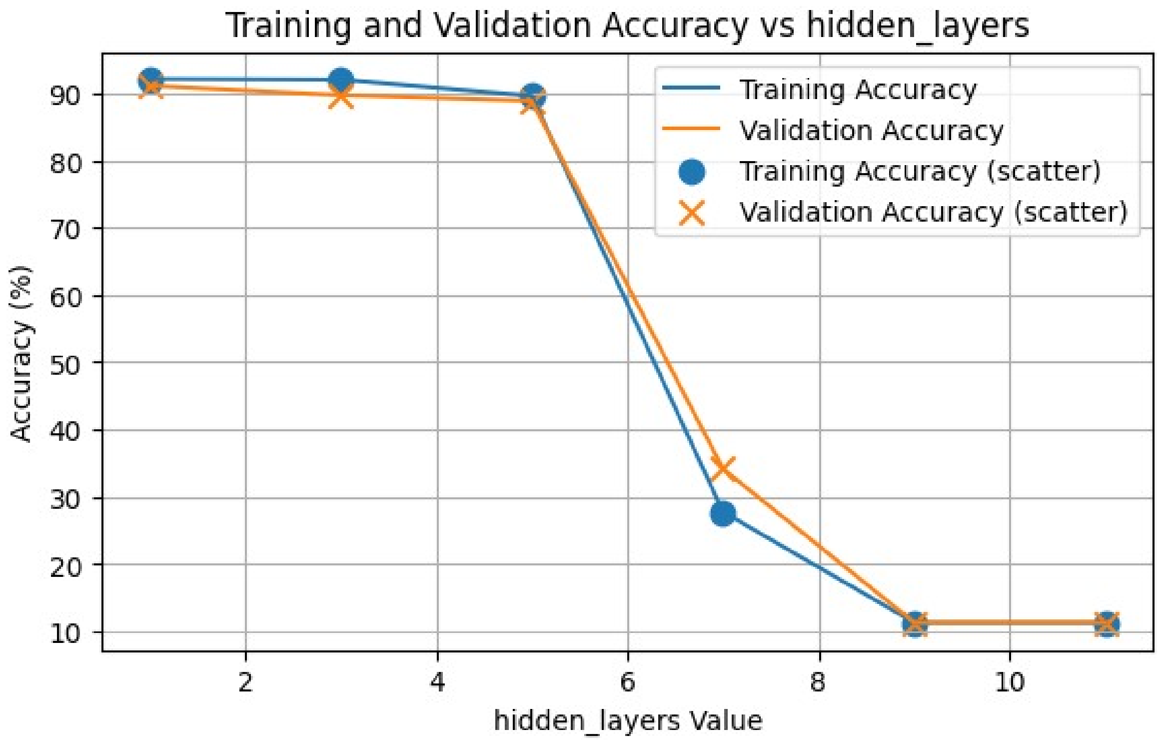
```python
import pandas as pd

# Convert the results list to a DataFrame
df = pd.DataFrame(results)

# Inspect the columns to ensure they match expected names
print("Columns in DataFrame:", df.columns)

# Verify sample rows to confirm data integrity
print(df.head())
```

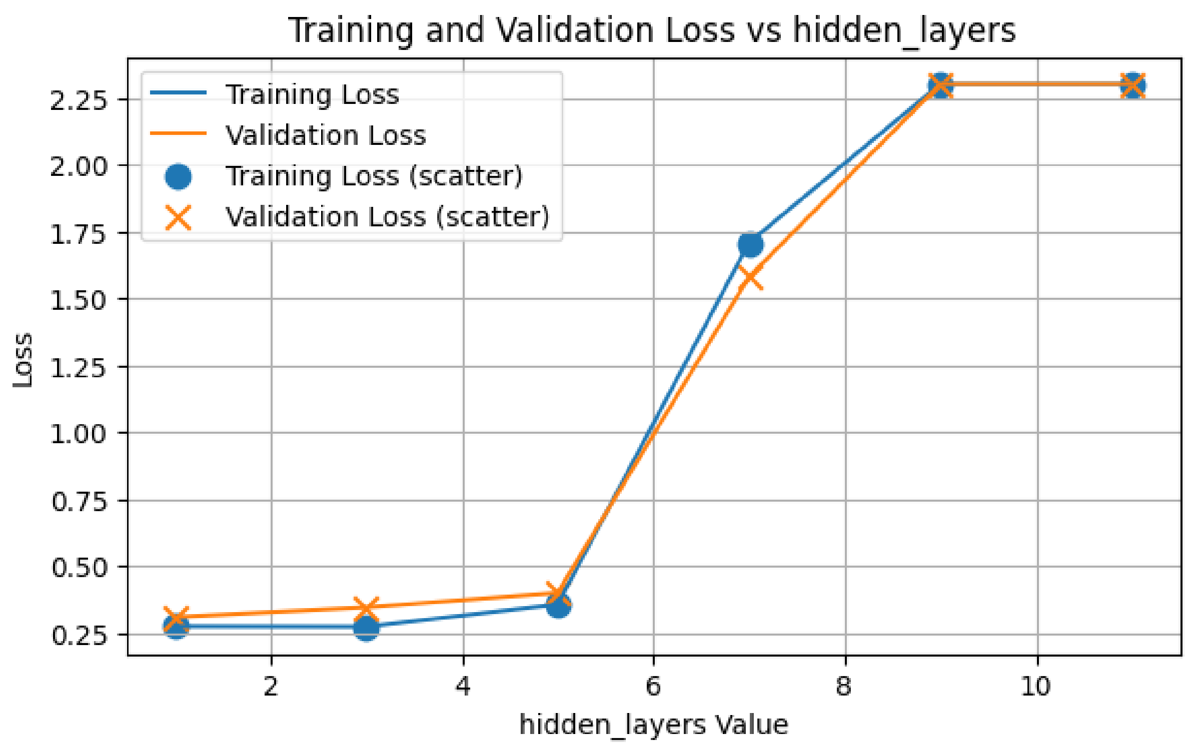
```
Columns in DataFrame: Index(['param', 'value', 'train_accuracy',
'val_accuracy', 'train_loss',
       'val_loss', 'y_true', 'y_pred'],
      dtype='object')
           param  value  train_accuracy  val_accuracy  train_loss
val_loss  \
0  hidden_layers    1.0       92.130952     91.135714    0.272497
0.306914
1  hidden_layers    3.0       92.021429     89.721429    0.271163
0.343308
2  hidden_layers    5.0       89.633333     88.857143    0.353852
0.397629
3  hidden_layers    7.0       27.730952     34.135714    1.707313
1.579375
4  hidden_layers    9.0       11.252381     11.257143    2.301109
2.300940

                                              y_true  \
0  [3, 6, 1, 0, 3, 3, 6, 4, 0, 4, 3, 9, 1, 8, 1, ...
1  [3, 6, 1, 0, 3, 3, 6, 4, 0, 4, 3, 9, 1, 8, 1, ...
2  [3, 6, 1, 0, 3, 3, 6, 4, 0, 4, 3, 9, 1, 8, 1, ...
3  [3, 6, 1, 0, 3, 3, 6, 4, 0, 4, 3, 9, 1, 8, 1, ...
4  [3, 6, 1, 0, 3, 3, 6, 4, 0, 4, 3, 9, 1, 8, 1, ...

                                              y_pred
0  [3, 6, 1, 0, 8, 3, 6, 4, 0, 4, 2, 9, 1, 8, 1, ...
1  [5, 6, 1, 0, 7, 5, 6, 4, 0, 7, 8, 9, 1, 8, 1, ...
2  [8, 2, 1, 6, 1, 8, 8, 1, 8, 1, 1, 1, 1, 2, 1, ...
3  [1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, ...
4  [1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, ...
```

```python
import matplotlib.pyplot as plt
from sklearn.metrics import confusion_matrix

# Plot Training & Validation Accuracy and Loss for each parameter
separately
unique_params = df["param"].unique()

for param in unique_params:
    # Filter the DataFrame for the current parameter
    subset = df[df["param"] == param]

    print(f"--------------------------------------------- Accuracy and
Loss for {param} -------------------------------------------- ")

    # Plot Training and Validation Accuracy on the same graph
    plt.figure(figsize=(7, 4))
    plt.plot(subset["value"], subset["train_accuracy"], linestyle='-',
label="Training Accuracy")
    plt.plot(subset["value"], subset["val_accuracy"], linestyle='-',
```

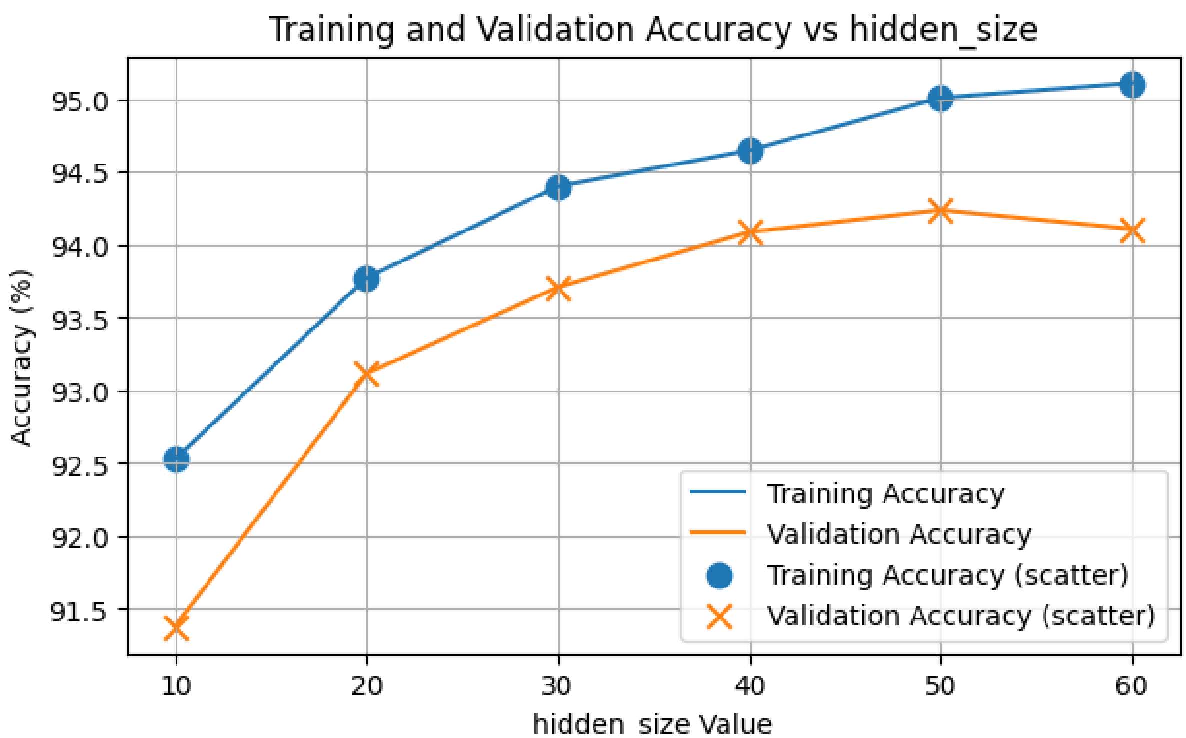
```
label="Validation Accuracy")
    plt.scatter(subset["value"], subset["train_accuracy"], marker='o',
s=80, label="Training Accuracy (scatter)")
    plt.scatter(subset["value"], subset["val_accuracy"], marker='x',
s=80, label="Validation Accuracy (scatter)")
    plt.title(f"Training and Validation Accuracy vs {param}")
    plt.xlabel(f"{param} Value")
    plt.ylabel("Accuracy (%)")
    plt.grid()
    plt.legend()
    plt.show()

    # Plot Training and Validation Loss on the same graph
    plt.figure(figsize=(7, 4))
    plt.plot(subset["value"], subset["train_loss"], linestyle='-',
label="Training Loss")
    plt.plot(subset["value"], subset["val_loss"], linestyle='-',
label="Validation Loss")
    plt.scatter(subset["value"], subset["train_loss"], marker='o',
s=80, label="Training Loss (scatter)")
    plt.scatter(subset["value"], subset["val_loss"], marker='x', s=80,
label="Validation Loss (scatter)")
    plt.title(f"Training and Validation Loss vs {param}")
    plt.xlabel(f"{param} Value")
    plt.ylabel("Loss")
    plt.grid()
    plt.legend()
    plt.show()

print(f"--------------------------------------------- Confusion Matrix
for {param} -------------------------------------------- ")

# Plot confusion matrix for each trained model
def plot_confusion_matrix(y_true, y_pred, param, value):
    cm = confusion_matrix(y_true, y_pred)
    plt.figure(figsize=(7, 4))
    sns.heatmap(cm, annot=True, fmt="d", cmap="Blues",
xticklabels=range(10), yticklabels=range(10))
    plt.title(f'Confusion Matrix for {param} = {value}')
    plt.xlabel('Predicted')
    plt.ylabel('True')
    plt.show()

# Generate confusion matrices for each parameter and value
for idx, row in df.iterrows():
    plot_confusion_matrix(row["y_true"], row["y_pred"], row["param"],
row["value"])
```

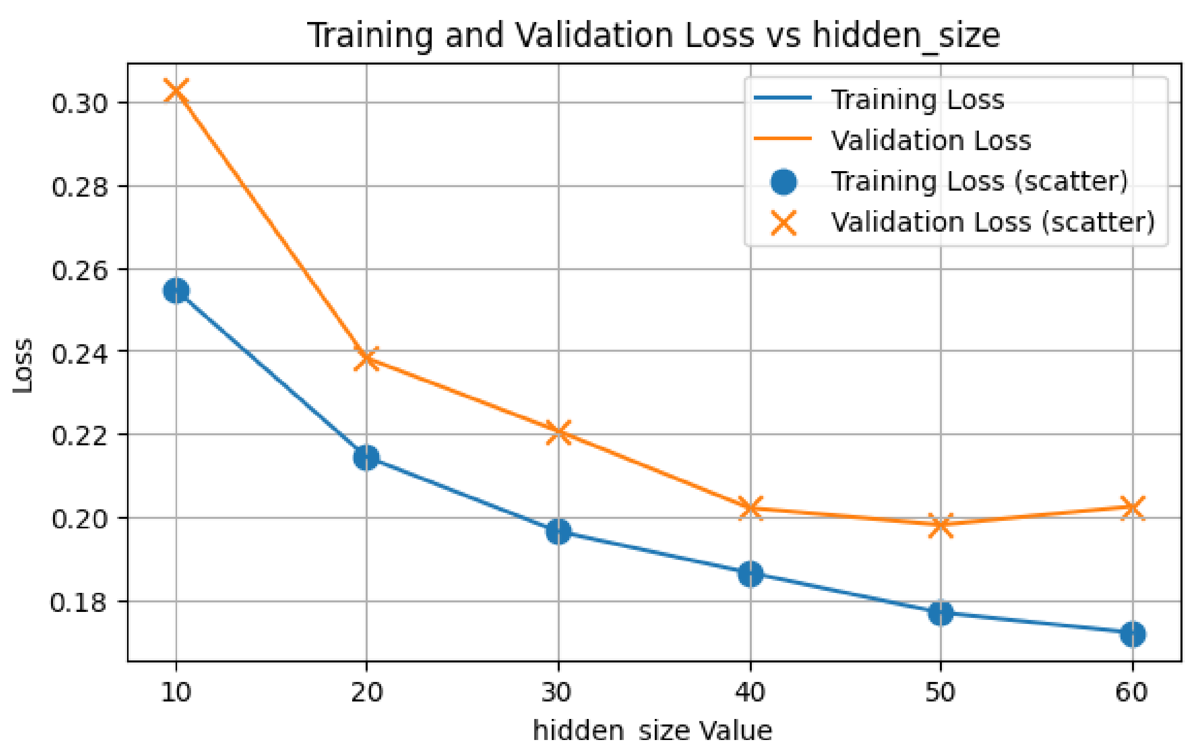
```
--------------------------------------------- Accuracy and Loss for
hidden_layers --------------------------------------------
```



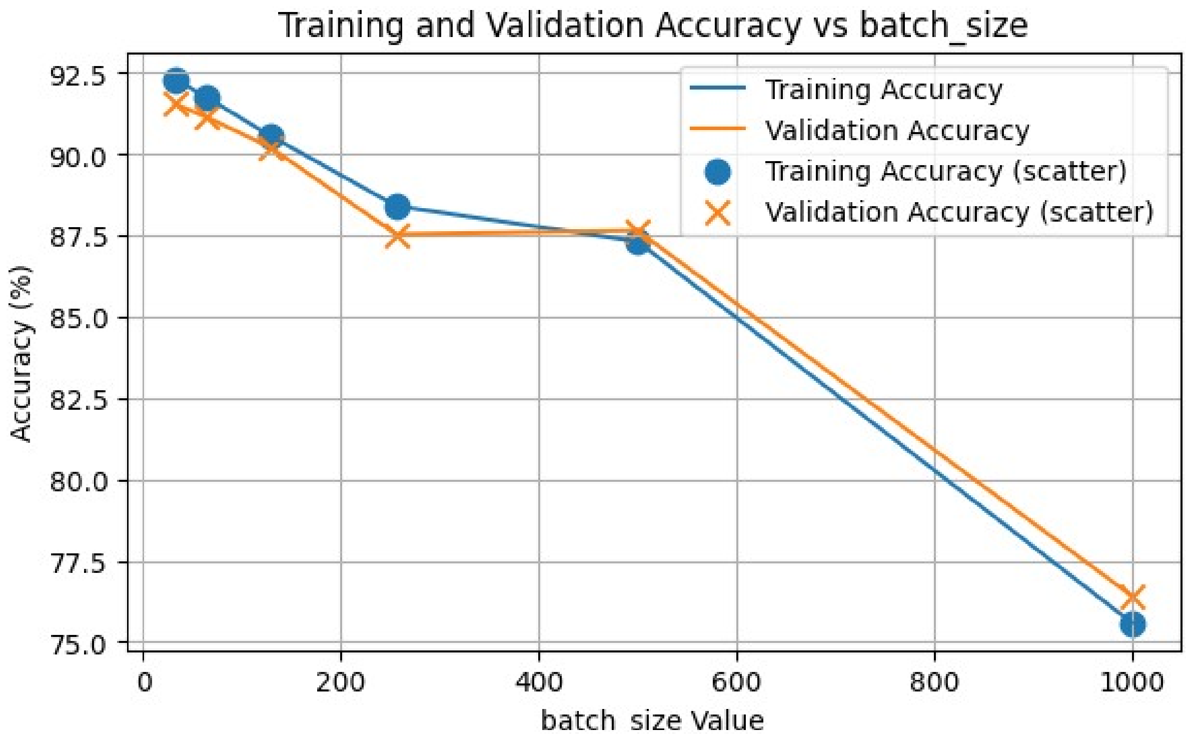


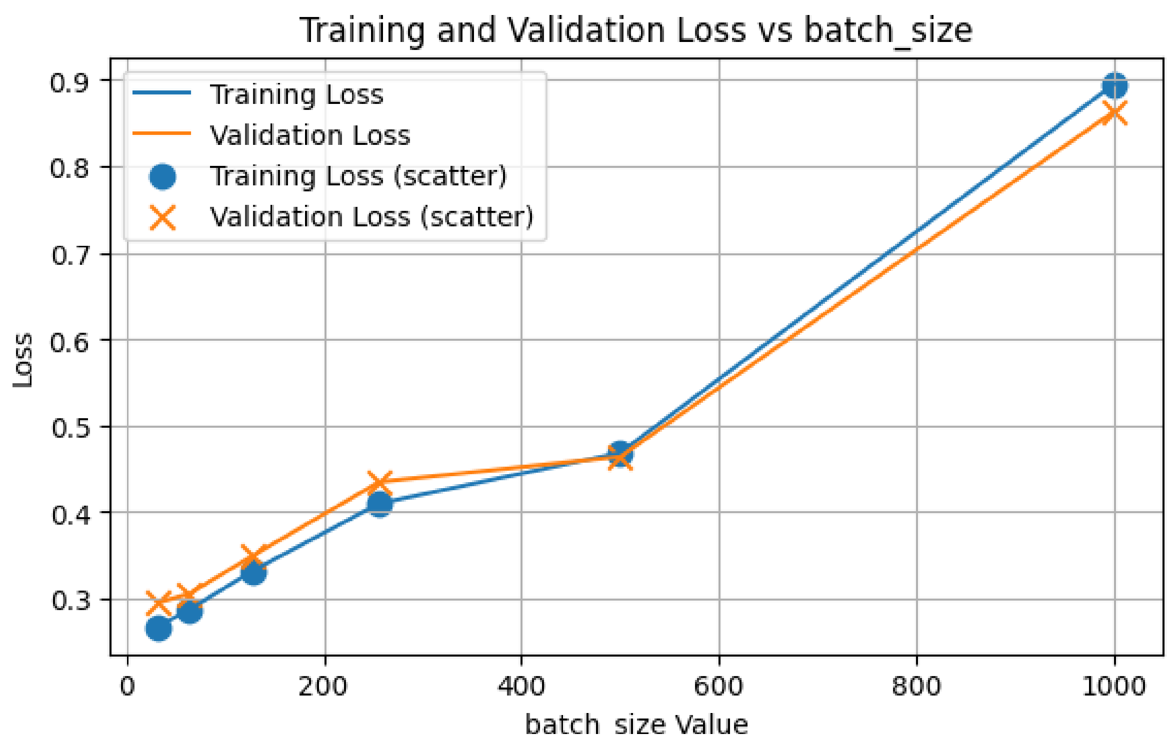

```
---------------------------------------------- Accuracy and Loss for
hidden_size ---------------------------------------------
```



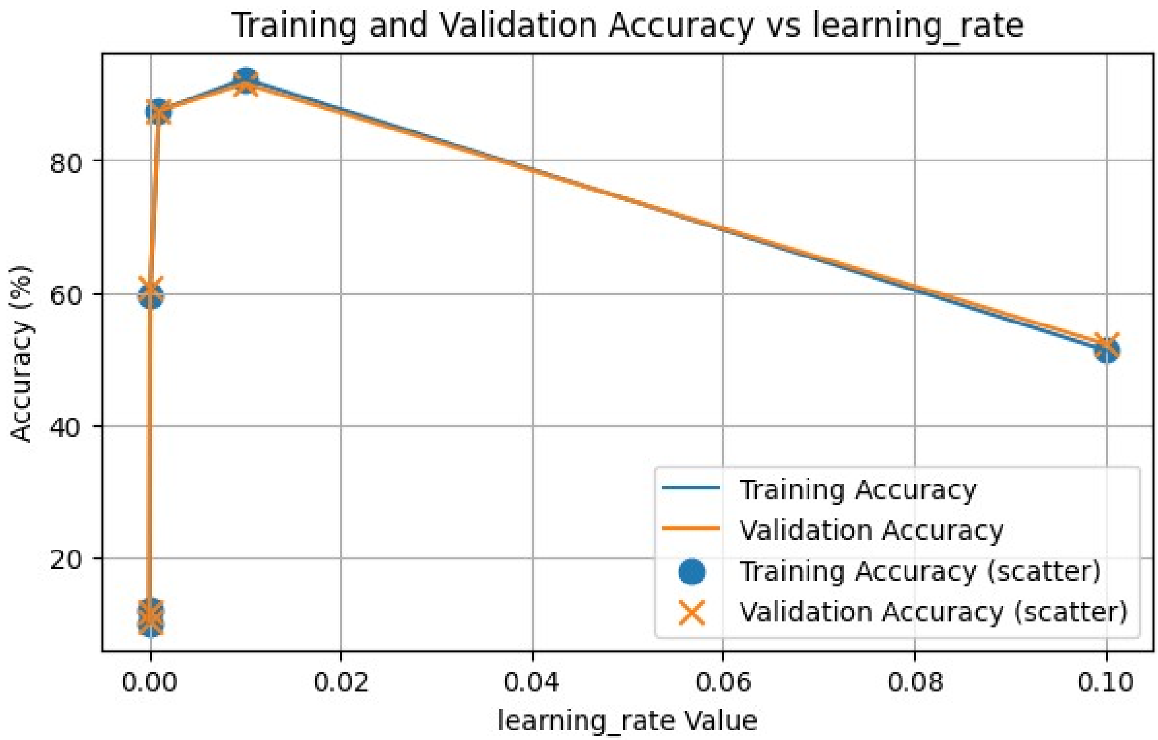


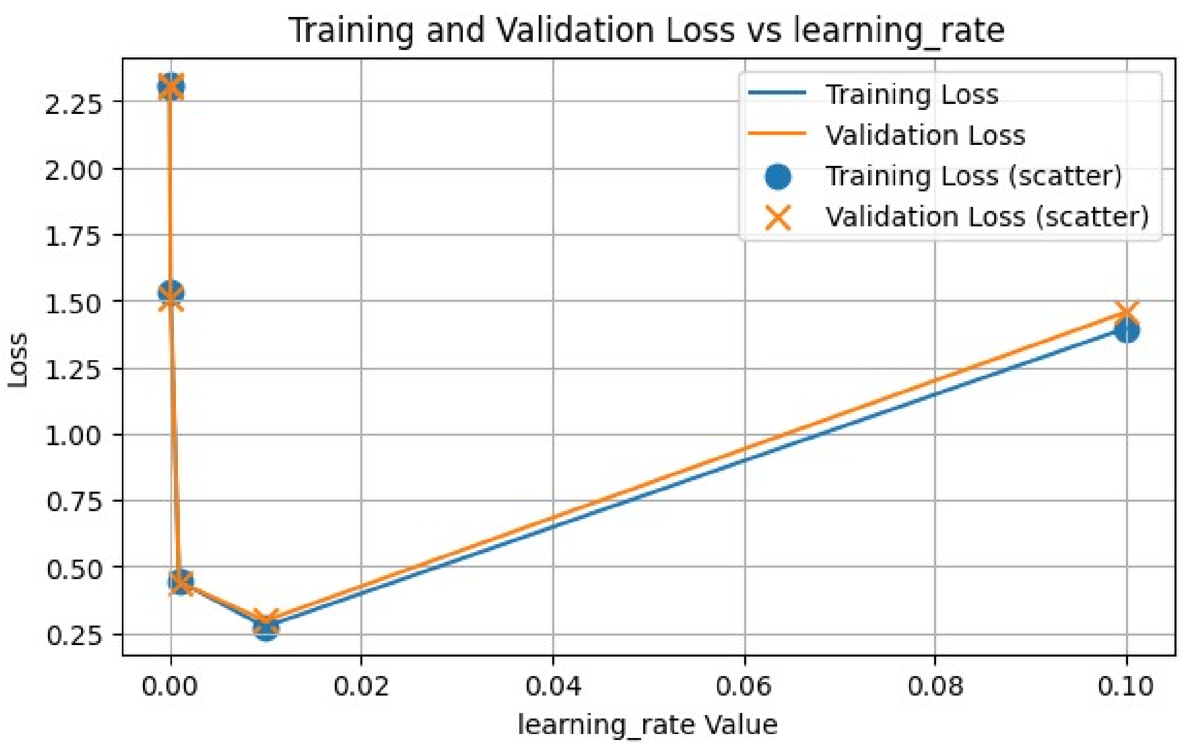

```
---------------------------------------------- Accuracy and Loss for
batch_size ---------------------------------------------
```



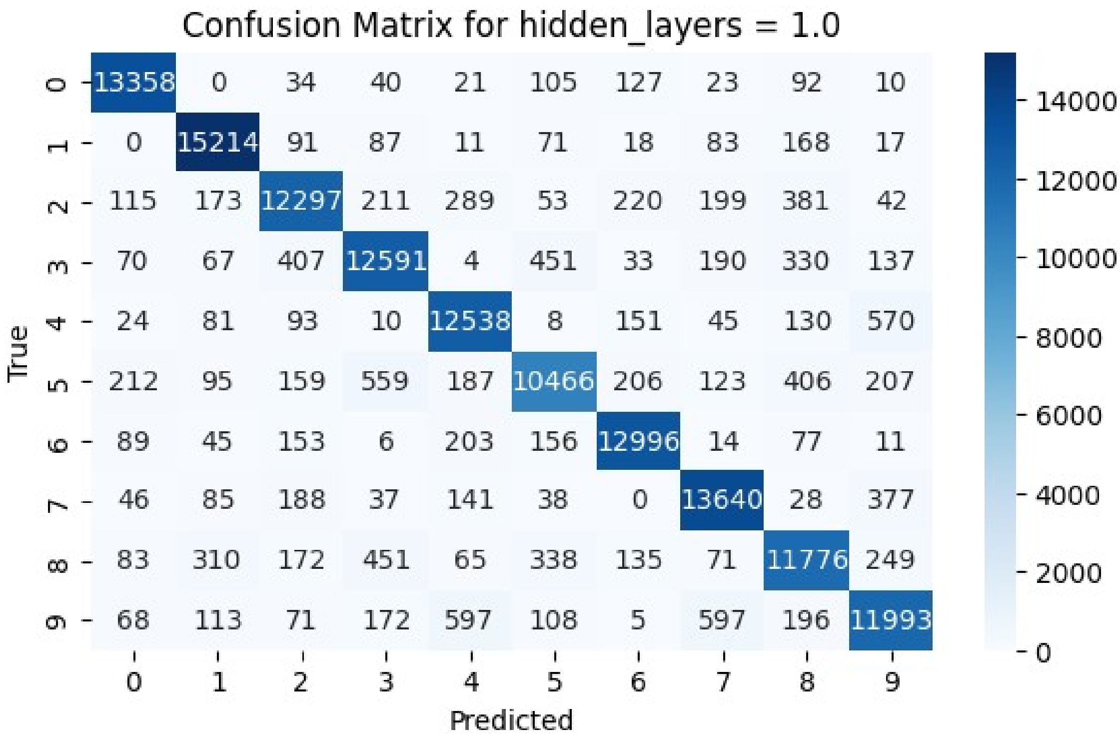


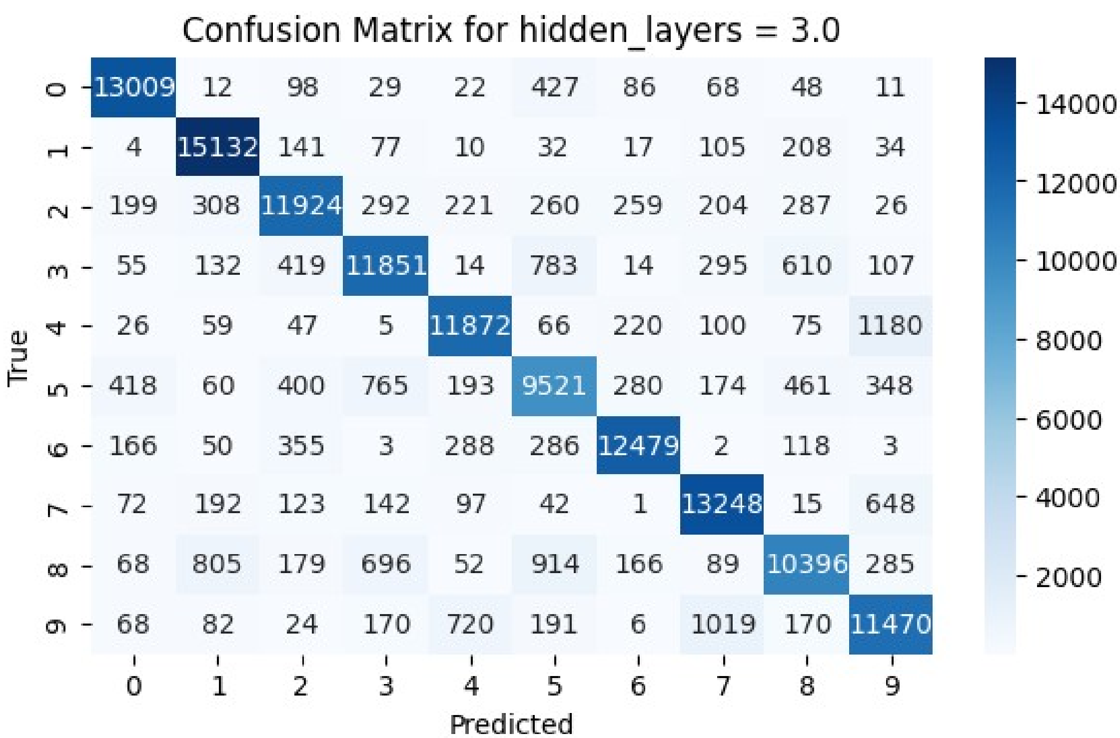

```
----------------------------------------- Accuracy and Loss for
learning_rate -----------------------------------------
```

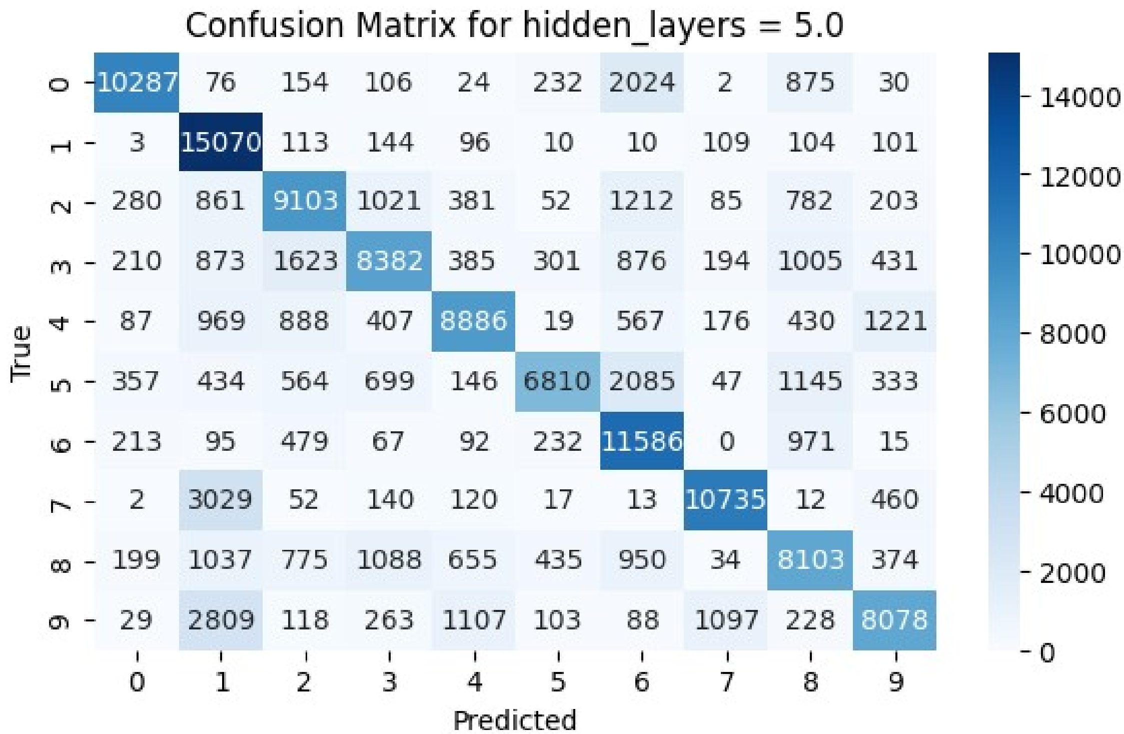


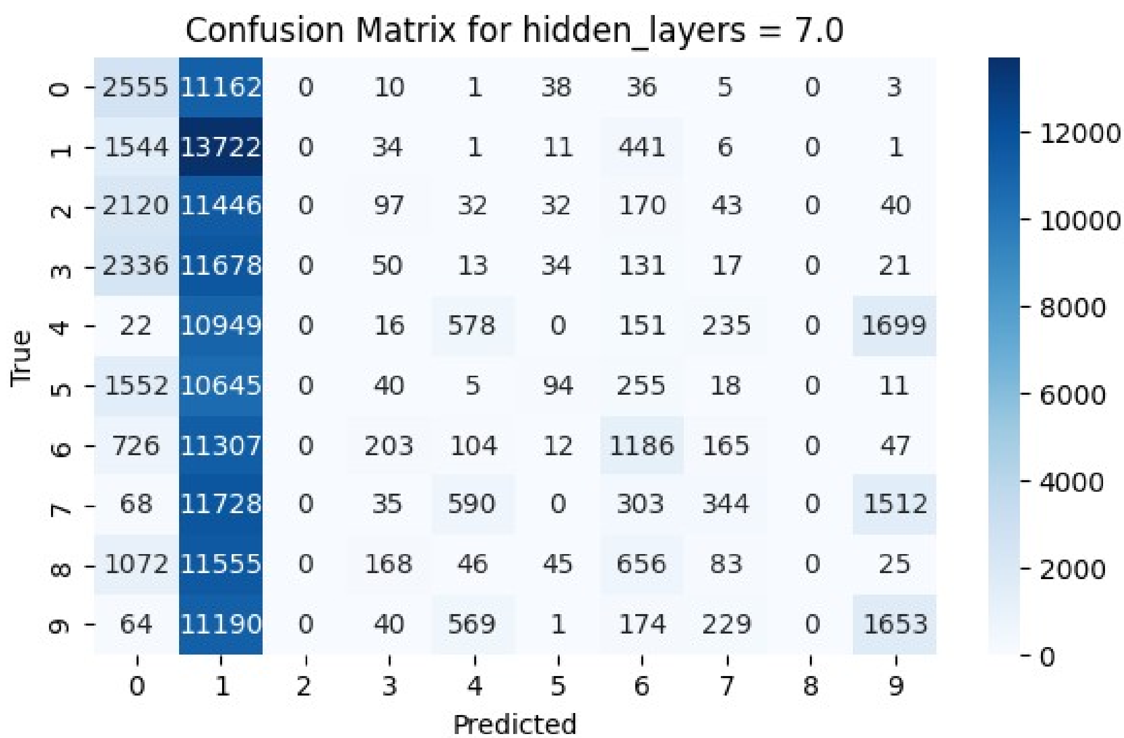


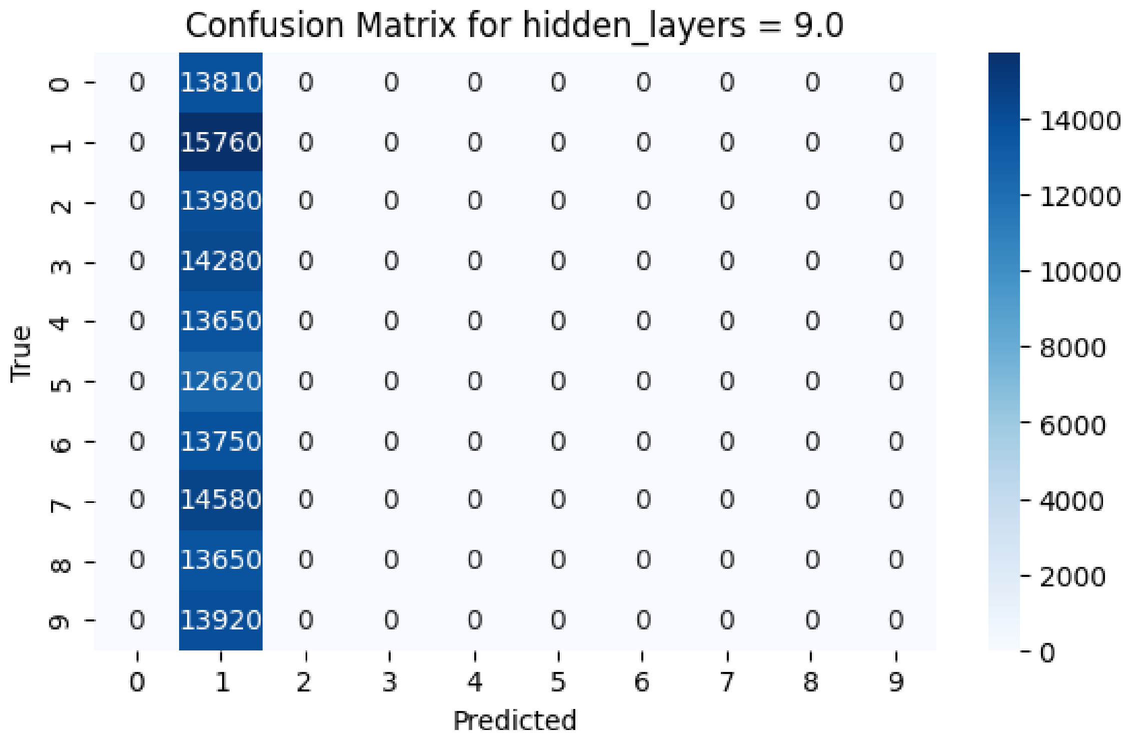

```
------------------------------------------ Confusion Matrix for
learning_rate ------------------------------------------
```

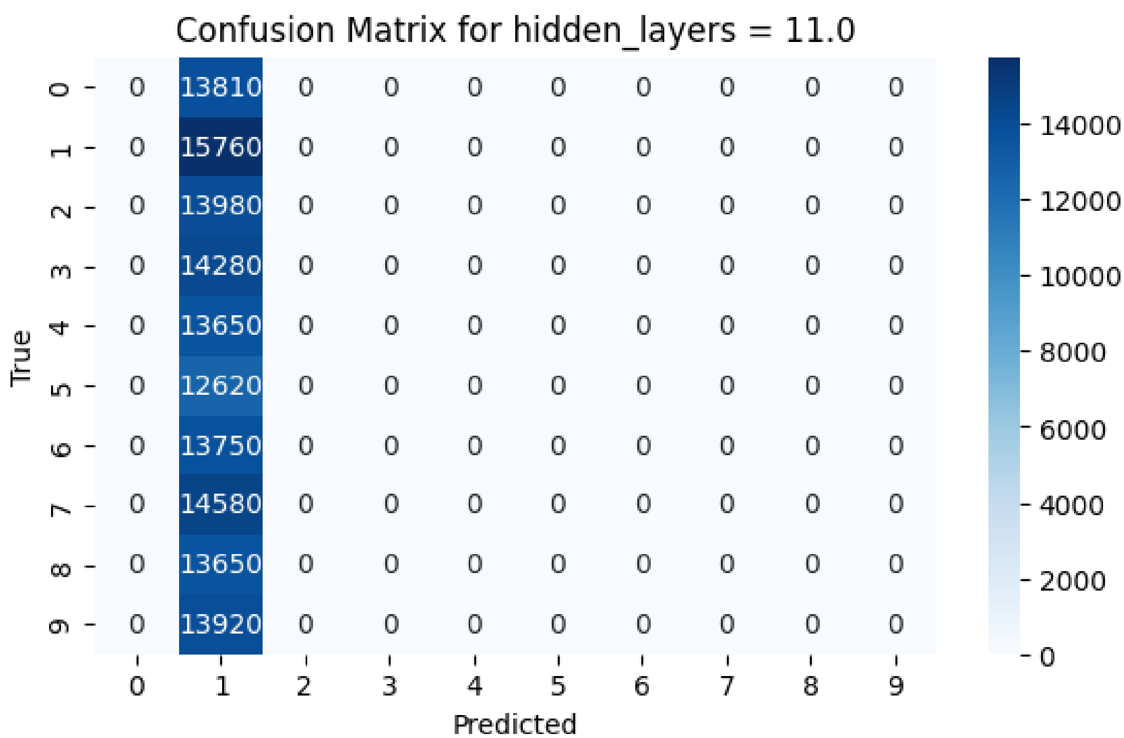

Confusion Matrix for hidden_layers = 1.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
13358 0 34 40 21 105 127 23 92 10
0 15214 91 87 11 71 18 83 168 17
115 173 12297 211 289 53 220 199 381 42
70 67 407 12591 4 451 33 190 330 137
24 81 93 10 12538 8 151 45 130 570
212 95 159 559 187 10466 206 123 406 207
89 45 153 6 203 156 12996 14 77 11
46 85 188 37 141 38 0 13640 28 377
83 310 172 451 65 338 135 71 11776 249
68 113 71 172 597 108 5 597 196 11993
0 2000 4000 6000 8000 10000 12000 14000

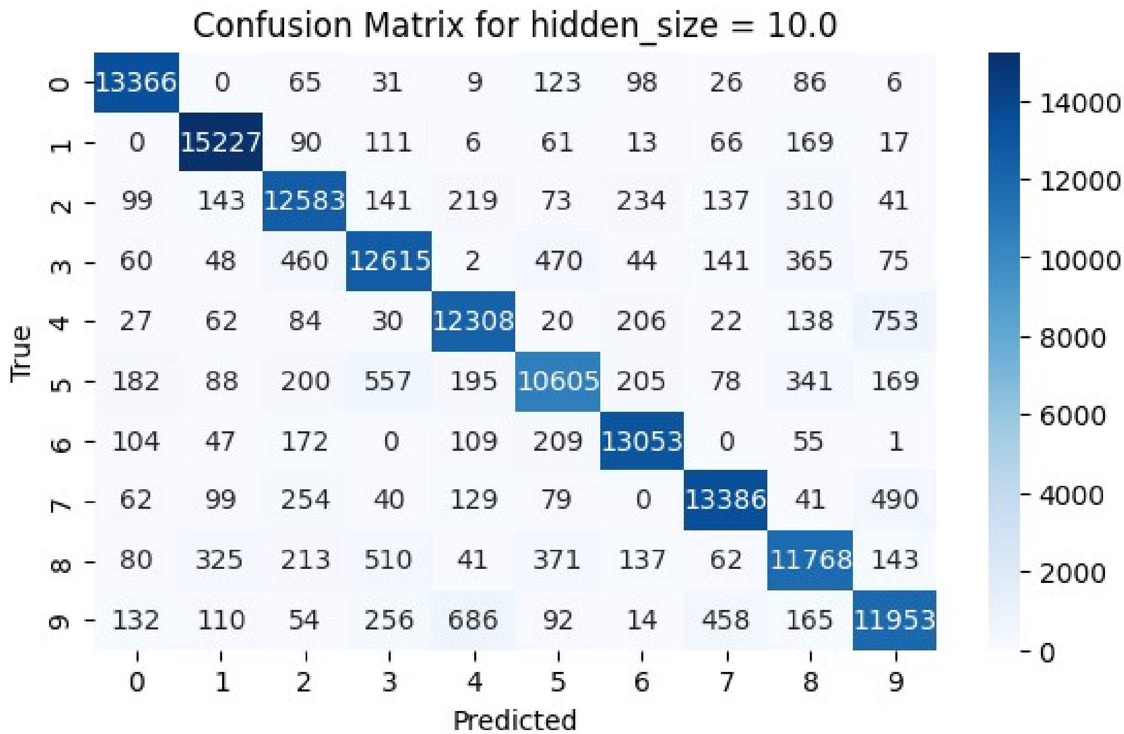

Confusion Matrix for hidden_layers = 3.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
13009 12 98 29 22 427 86 68 48 11
4 15132 141 77 10 32 17 105 208 34
199 308 11924 292 221 260 259 204 287 26
55 132 419 11851 14 783 14 295 610 107
26 59 47 5 11872 66 220 100 75 1180
418 60 400 765 193 9521 280 174 461 348
166 50 355 3 288 286 12479 2 118 3
72 192 123 142 97 42 1 13248 15 648
68 805 179 696 52 914 166 89 10396 285
68 82 24 170 720 191 6 1019 170 11470
2000 4000 6000 8000 10000 12000 14000

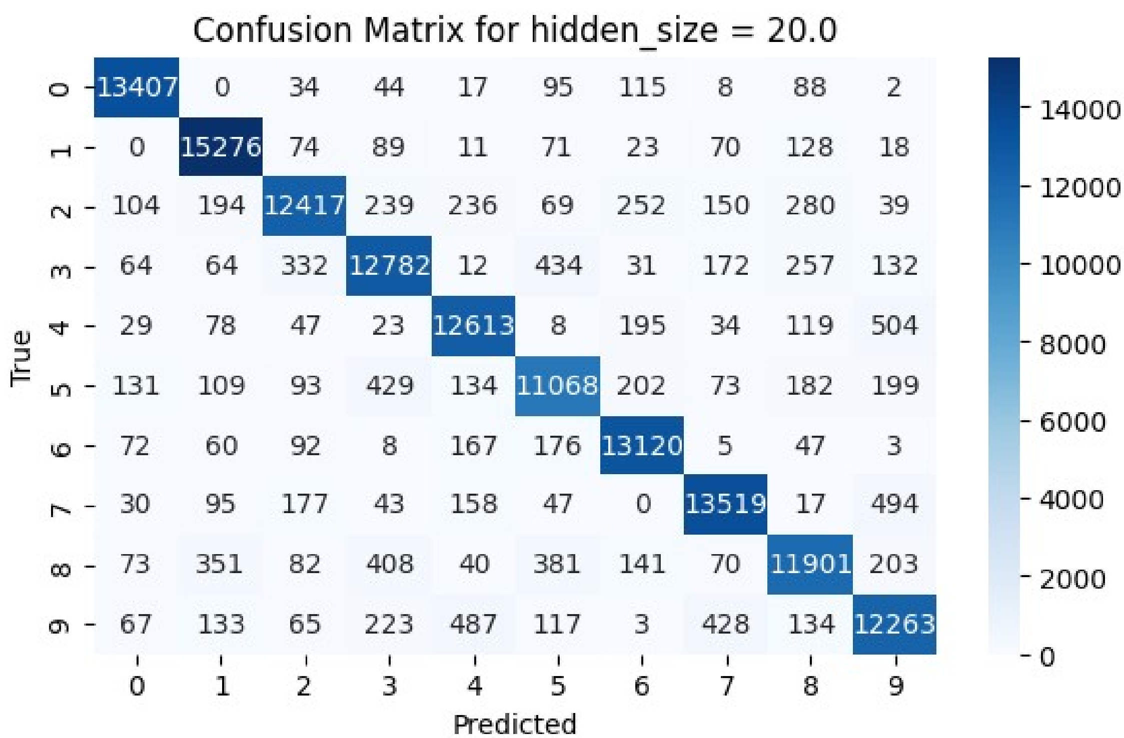

Confusion Matrix for hidden_layers = 5.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
0 10287 76 154 106 24 232 2024 2 875 30
1 3 15070 113 144 96 10 10 109 104 101
2 280 861 9103 1021 381 52 1212 85 782 203
3 210 873 1623 8382 385 301 876 194 1005 431
4 87 969 888 407 8886 19 567 176 430 1221
5 357 434 564 699 146 6810 2085 47 1145 333
6 213 95 479 67 92 232 11586 0 971 15
7 2 3029 52 140 120 17 13 10735 12 460
8 199 1037 775 1088 655 435 950 34 8103 374
9 29 2809 118 263 1107 103 88 1097 228 8078
14000
12000
10000
8000
6000
4000
2000
0

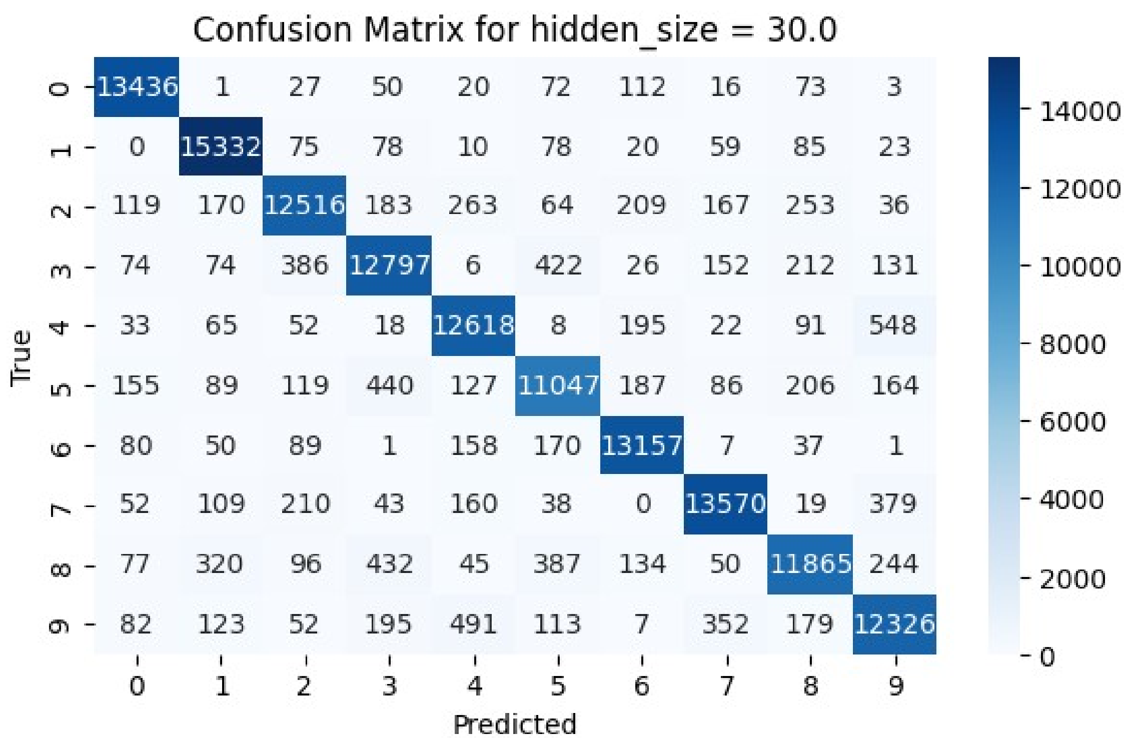

Confusion Matrix for hidden_layers = 7.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
0 2555 11162 0 10 1 38 36 5 0 3
1 1544 13722 0 34 1 11 441 6 0 1
2 2120 11446 0 97 32 32 170 43 0 40
3 2336 11678 0 50 13 34 131 17 0 21
4 22 10949 0 16 578 0 151 235 0 1699
5 1552 10645 0 40 5 94 255 18 0 11
6 726 11307 0 203 104 12 1186 165 0 47
7 68 11728 0 35 590 0 303 344 0 1512
8 1072 11555 0 168 46 45 656 83 0 25
9 64 11190 0 40 569 1 174 229 0 1653
12000
10000
8000
6000
4000
2000
0

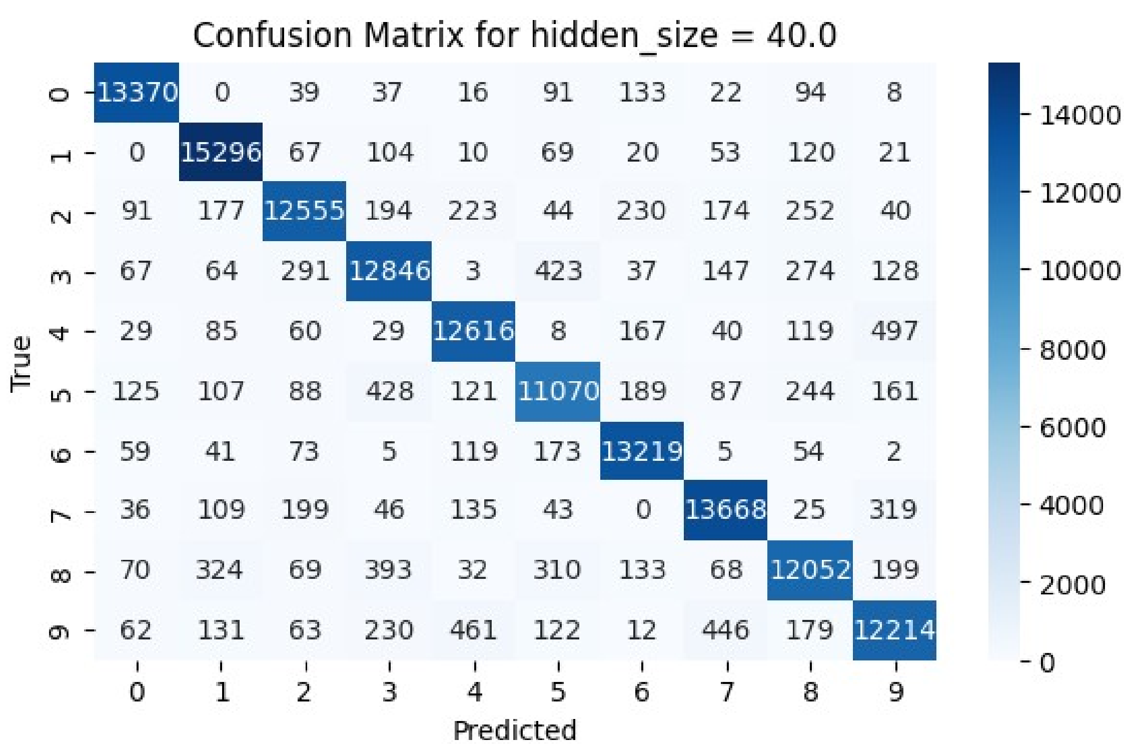

Confusion Matrix for hidden_layers = 9.0
True
Predicted
13810
15760
13980
14280
13650
12620
13750
14580
13650
13920

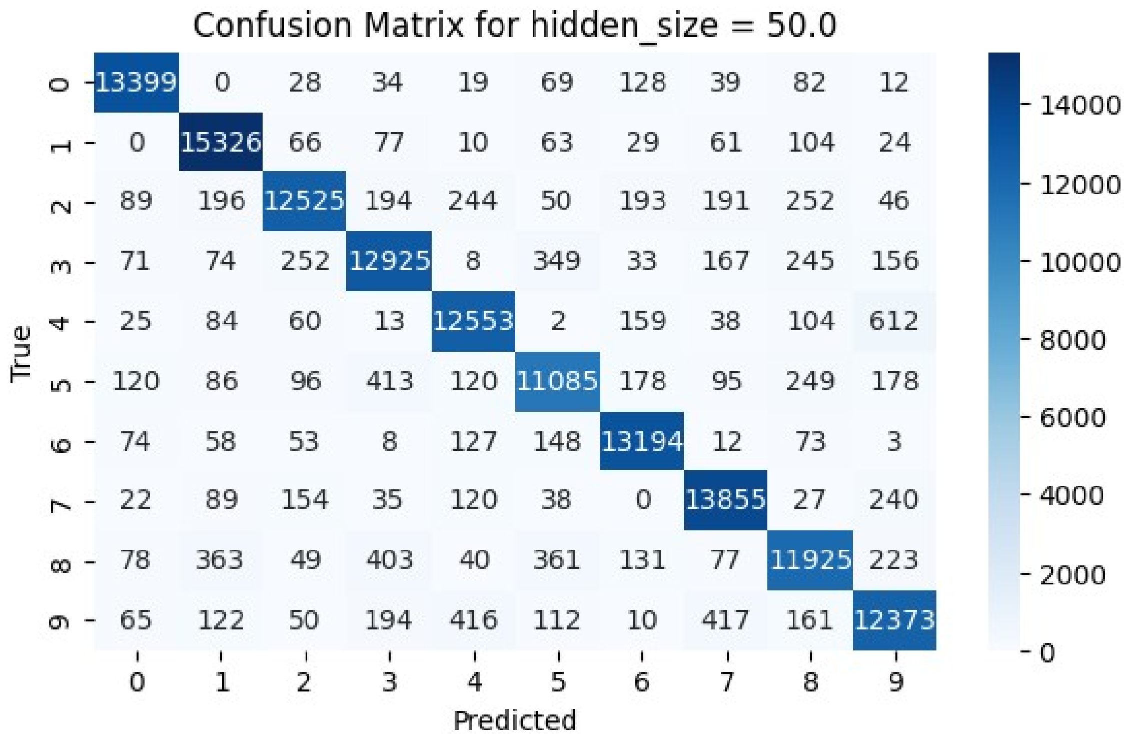

Confusion Matrix for hidden_layers = 11.0
True
Predicted
13810
15760
13980
14280
13650
12620
13750
14580
13650
13920

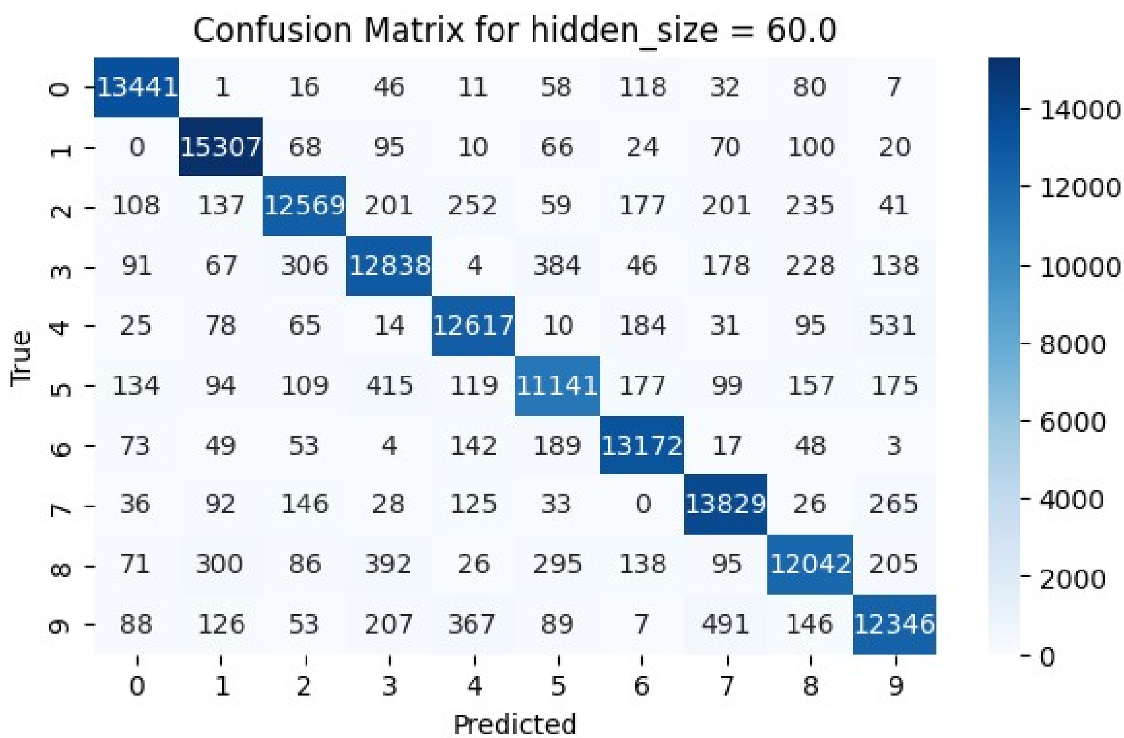

Confusion Matrix for hidden_size = 10.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
0: 13366 0 65 31 9 123 98 26 86 6
1: 0 15227 90 111 6 61 13 66 169 17
2: 99 143 12583 141 219 73 234 137 310 41
3: 60 48 460 12615 2 470 44 141 365 75
4: 27 62 84 30 12308 20 206 22 138 753
5: 182 88 200 557 195 10605 205 78 341 169
6: 104 47 172 0 109 209 13053 0 55 1
7: 62 99 254 40 129 79 0 13386 41 490
8: 80 325 213 510 41 371 137 62 11768 143
9: 132 110 54 256 686 92 14 458 165 11953
14000
12000
10000
8000
6000
4000
2000
0

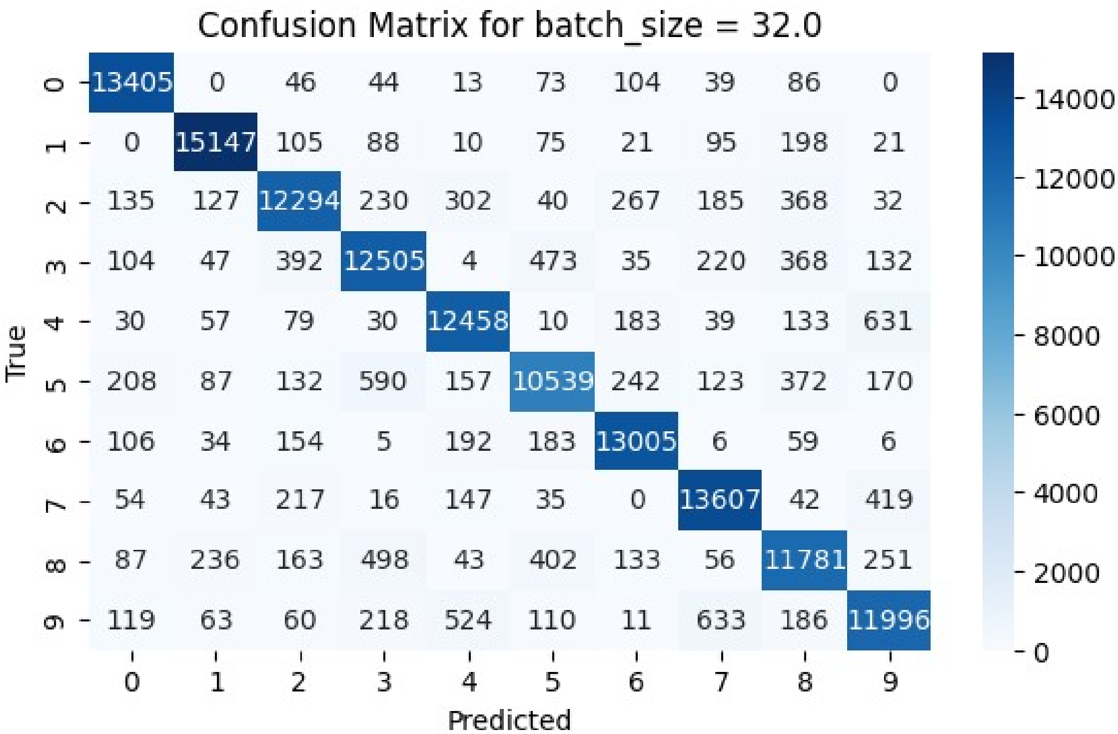

Confusion Matrix for hidden_size = 20.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
0: 13407 0 34 44 17 95 115 8 88 2
1: 0 15276 74 89 11 71 23 70 128 18
2: 104 194 12417 239 236 69 252 150 280 39
3: 64 64 332 12782 12 434 31 172 257 132
4: 29 78 47 23 12613 8 195 34 119 504
5: 131 109 93 429 134 11068 202 73 182 199
6: 72 60 92 8 167 176 13120 5 47 3
7: 30 95 177 43 158 47 0 13519 17 494
8: 73 351 82 408 40 381 141 70 11901 203
9: 67 133 65 223 487 117 3 428 134 12263
14000
12000
10000
8000
6000
4000
2000
0

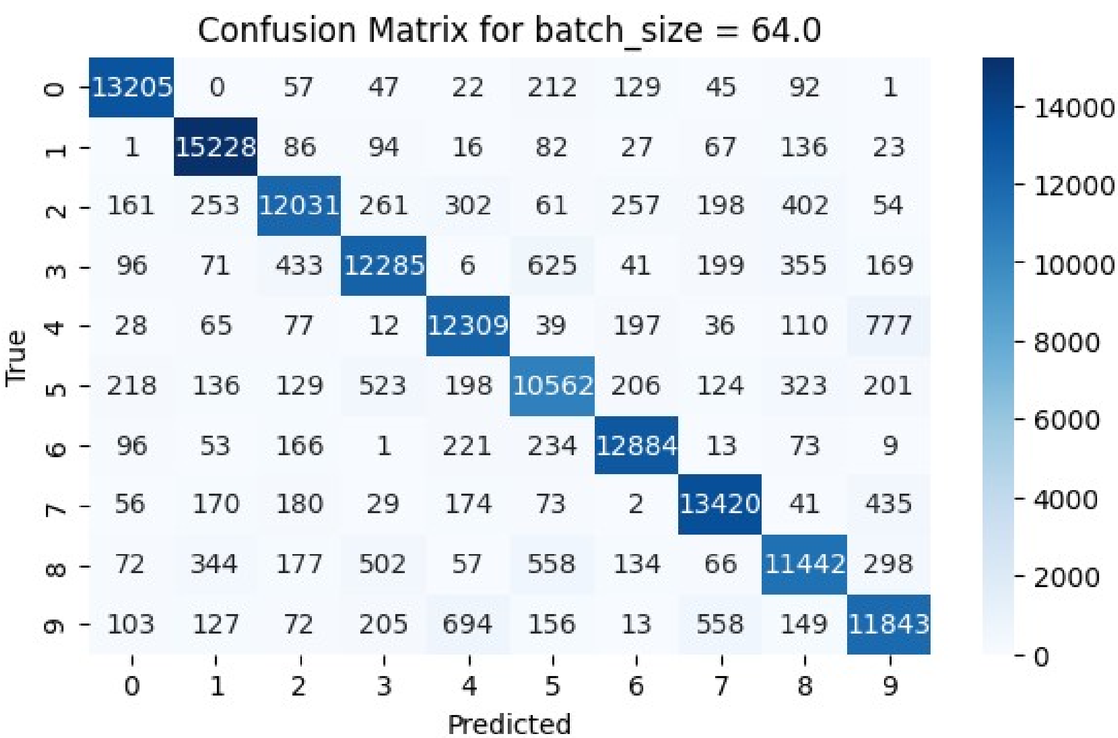

Confusion Matrix for hidden_size = 30.0
0: 13436 1 27 50 20 72 112 16 73 3
1: 0 15332 75 78 10 78 20 59 85 23
2: 119 170 12516 183 263 64 209 167 253 36
3: 74 74 386 12797 6 422 26 152 212 131
4: 33 65 52 18 12618 8 195 22 91 548
5: 155 89 119 440 127 11047 187 86 206 164
6: 80 50 89 1 158 170 13157 7 37 1
7: 52 109 210 43 160 38 0 13570 19 379
8: 77 320 96 432 45 387 134 50 11865 244
9: 82 123 52 195 491 113 7 352 179 12326
True
Predicted
0 1 2 3 4 5 6 7 8 9
14000
12000
10000
8000
6000
4000
2000
0

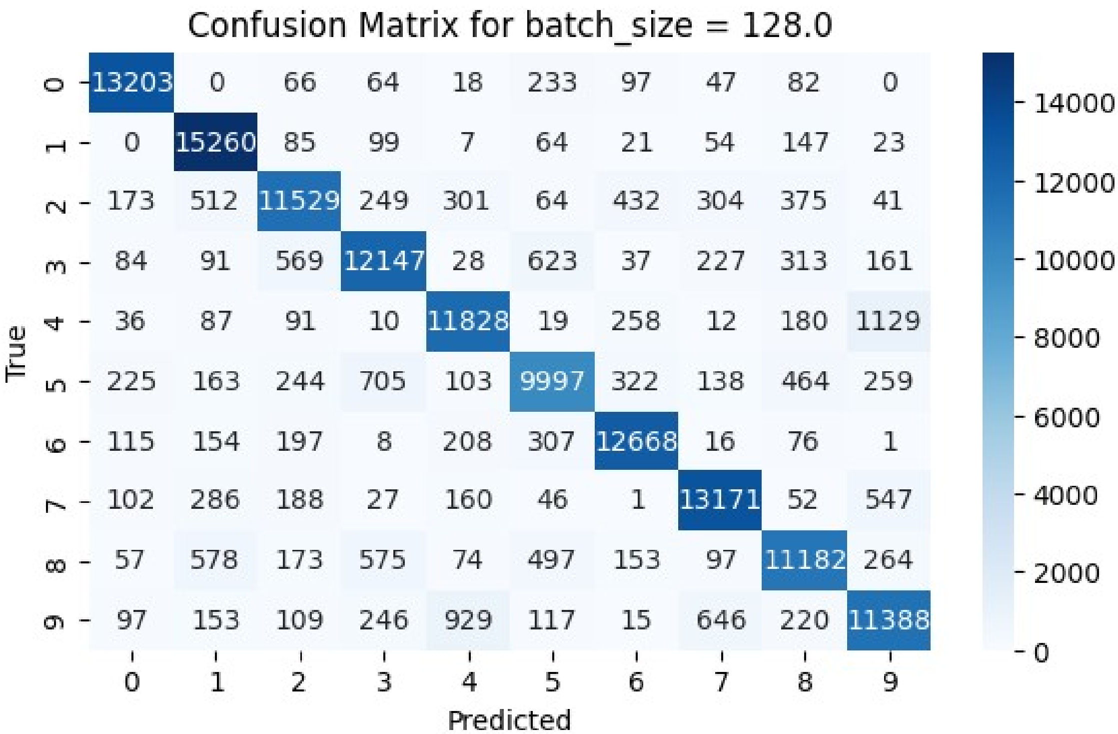

Confusion Matrix for hidden_size = 40.0
0: 13370 0 39 37 16 91 133 22 94 8
1: 0 15296 67 104 10 69 20 53 120 21
2: 91 177 12555 194 223 44 230 174 252 40
3: 67 64 291 12846 3 423 37 147 274 128
4: 29 85 60 29 12616 8 167 40 119 497
5: 125 107 88 428 121 11070 189 87 244 161
6: 59 41 73 5 119 173 13219 5 54 2
7: 36 109 199 46 135 43 0 13668 25 319
8: 70 324 69 393 32 310 133 68 12052 199
9: 62 131 63 230 461 122 12 446 179 12214
True
Predicted
0 1 2 3 4 5 6 7 8 9
14000
12000
10000
8000
6000
4000
2000
0


Confusion Matrix for hidden_size = 50.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
0 13399 0 28 34 19 69 128 39 82 12
1 0 15326 66 77 10 63 29 61 104 24
2 89 196 12525 194 244 50 193 191 252 46
3 71 74 252 12925 8 349 33 167 245 156
4 25 84 60 13 12553 2 159 38 104 612
5 120 86 96 413 120 11085 178 95 249 178
6 74 58 53 8 127 148 13194 12 73 3
7 22 89 154 35 120 38 0 13855 27 240
8 78 363 49 403 40 361 131 77 11925 223
9 65 122 50 194 416 112 10 417 161 12373
14000
12000
10000
8000
6000
4000
2000
0

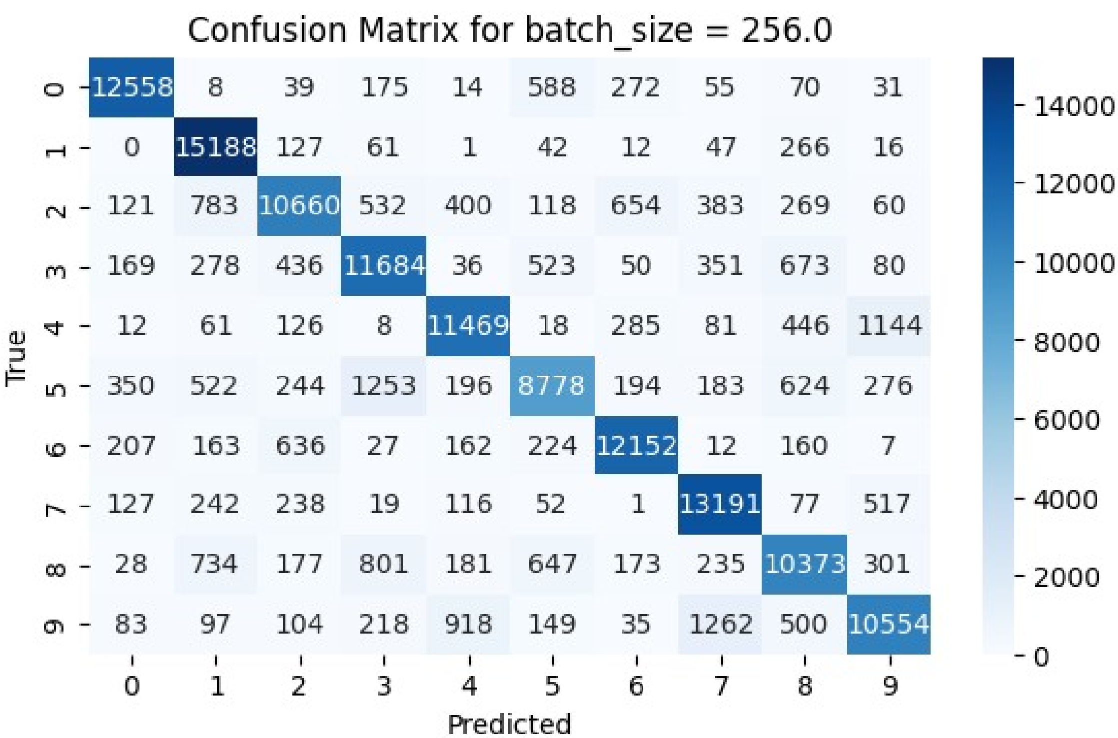

Confusion Matrix for hidden_size = 60.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
0 13441 1 16 46 11 58 118 32 80 7
1 0 15307 68 95 10 66 24 70 100 20
2 108 137 12569 201 252 59 177 201 235 41
3 91 67 306 12838 4 384 46 178 228 138
4 25 78 65 14 12617 10 184 31 95 531
5 134 94 109 415 119 11141 177 99 157 175
6 73 49 53 4 142 189 13172 17 48 3
7 36 92 146 28 125 33 0 13829 26 265
8 71 300 86 392 26 295 138 95 12042 205
9 88 126 53 207 367 89 7 491 146 12346
14000
12000
10000
8000
6000
4000
2000
0


Confusion Matrix for batch_size = 32.0
13405 0 46 44 13 73 104 39 86 0
0 15147 105 88 10 75 21 95 198 21
135 127 12294 230 302 40 267 185 368 32
104 47 392 12505 4 473 35 220 368 132
30 57 79 30 12458 10 183 39 133 631
208 87 132 590 157 10539 242 123 372 170
106 34 154 5 192 183 13005 6 59 6
54 43 217 16 147 35 0 13607 42 419
87 236 163 498 43 402 133 56 11781 251
119 63 60 218 524 110 11 633 186 11996
True
Predicted
0 1 2 3 4 5 6 7 8 9
0 2000 4000 6000 8000 10000 12000 14000

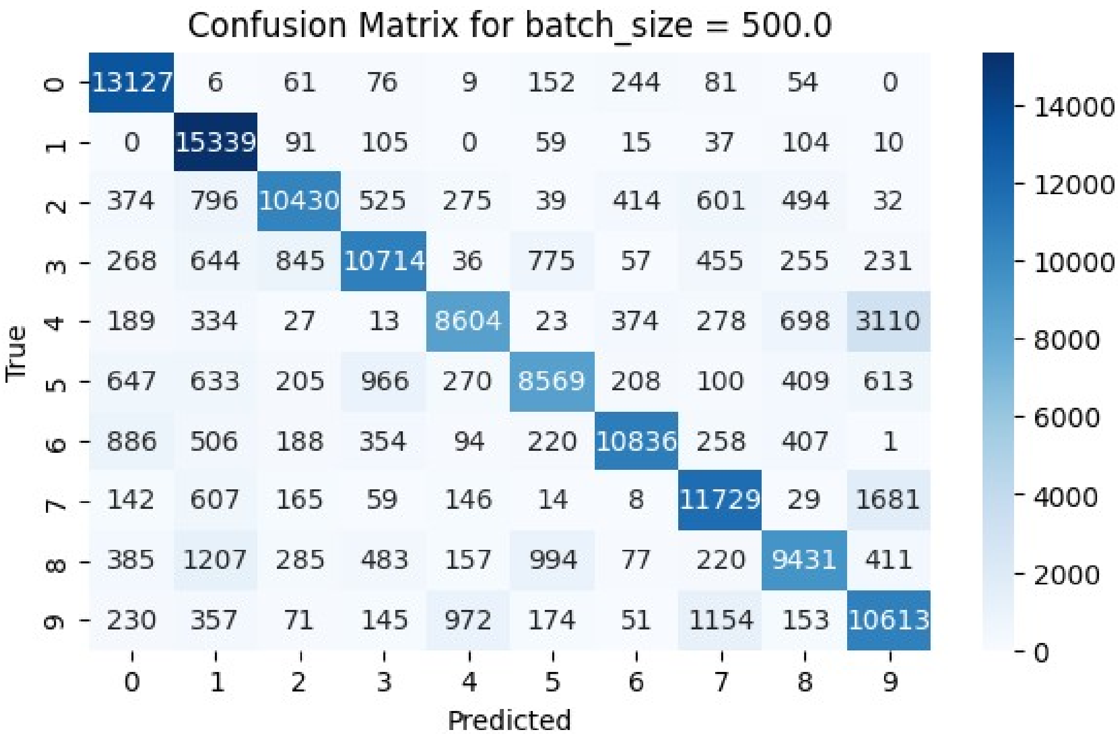

Confusion Matrix for batch_size = 64.0
13205 0 57 47 22 212 129 45 92 1
1 15228 86 94 16 82 27 67 136 23
161 253 12031 261 302 61 257 198 402 54
96 71 433 12285 6 625 41 199 355 169
28 65 77 12 12309 39 197 36 110 777
218 136 129 523 198 10562 206 124 323 201
96 53 166 1 221 234 12884 13 73 9
56 170 180 29 174 73 2 13420 41 435
72 344 177 502 57 558 134 66 11442 298
103 127 72 205 694 156 13 558 149 11843
True
Predicted
0 1 2 3 4 5 6 7 8 9
0 2000 4000 6000 8000 10000 12000 14000

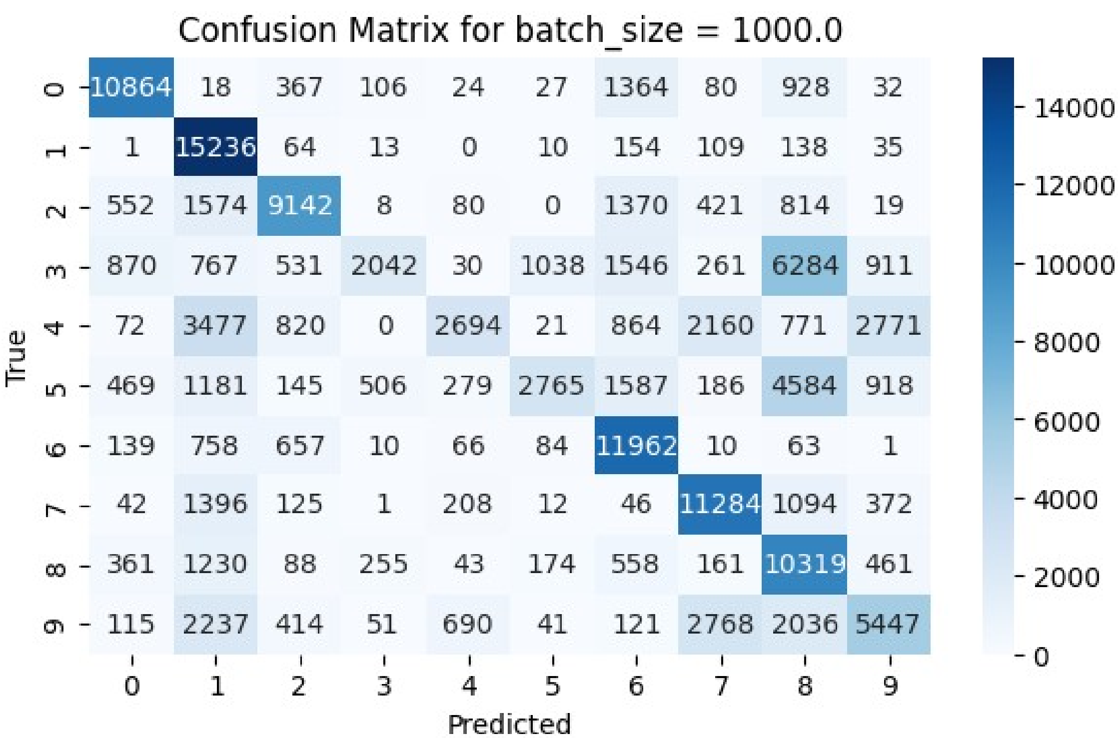


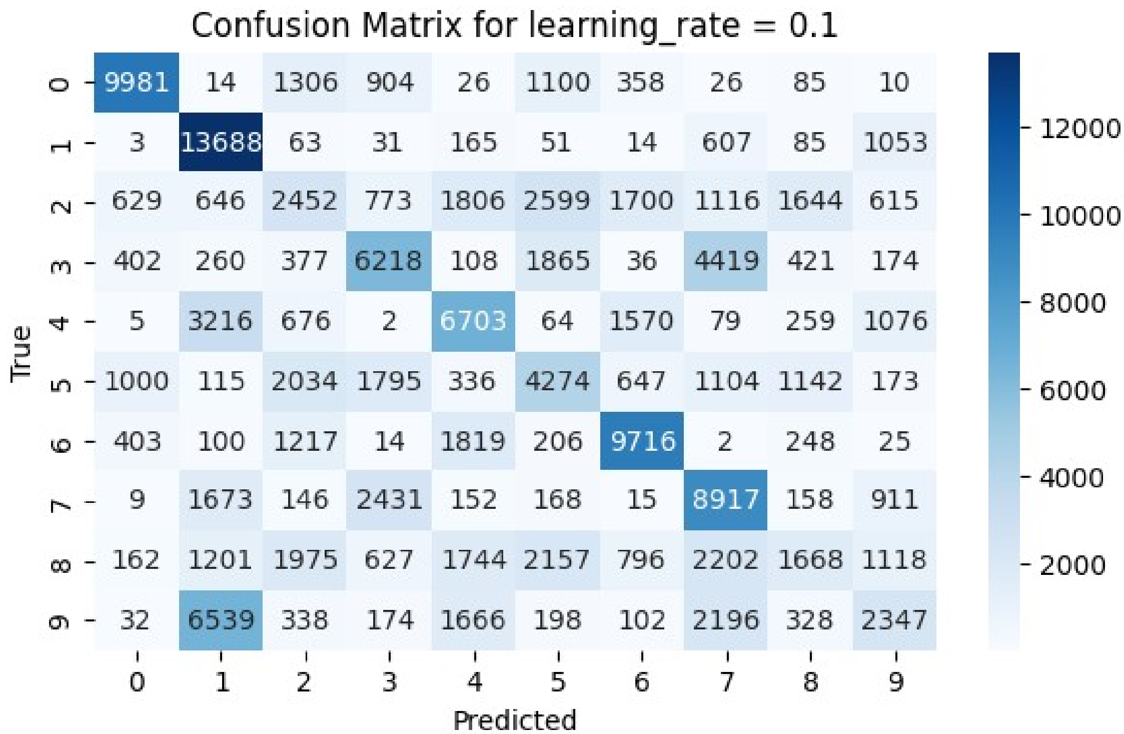
Confusion Matrix for batch_size = 128.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
0: 13203 0 66 64 18 233 97 47 82 0
1: 0 15260 85 99 7 64 21 54 147 23
2: 173 512 11529 249 301 64 432 304 375 41
3: 84 91 569 12147 28 623 37 227 313 161
4: 36 87 91 10 11828 19 258 12 180 1129
5: 225 163 244 705 103 9997 322 138 464 259
6: 115 154 197 8 208 307 12668 16 76 1
7: 102 286 188 27 160 46 1 13171 52 547
8: 57 578 173 575 74 497 153 97 11182 264
9: 97 153 109 246 929 117 15 646 220 11388
14000
12000
10000
8000
6000
4000
2000
0

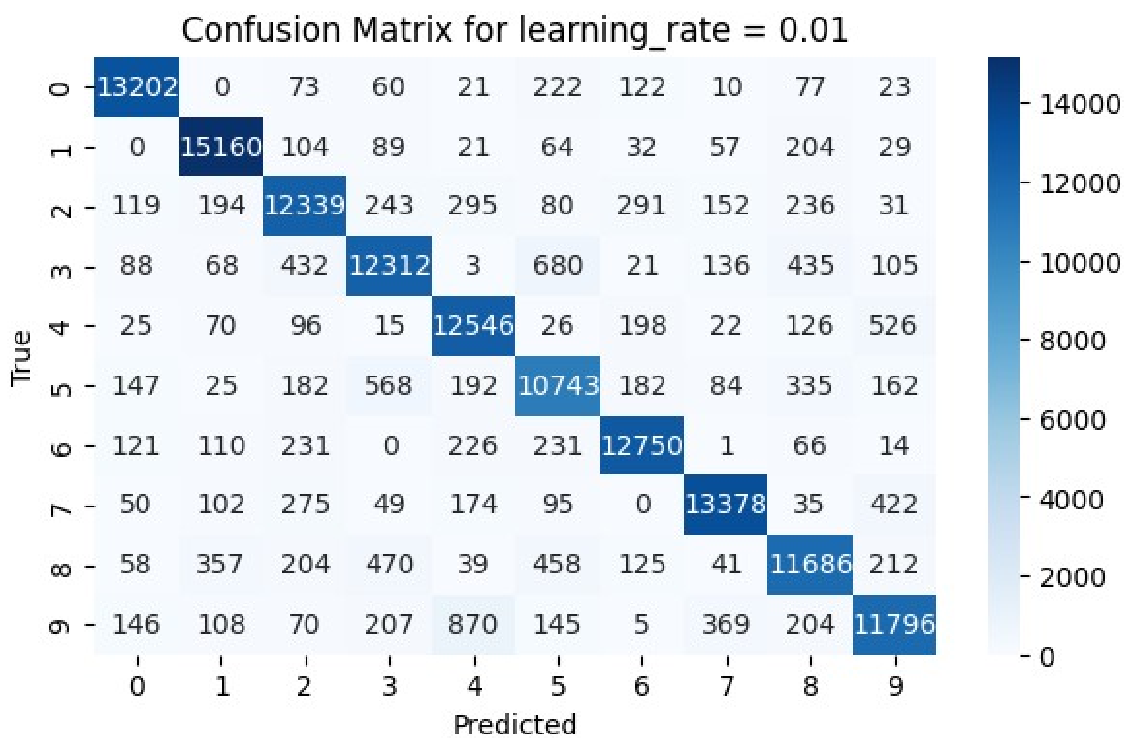


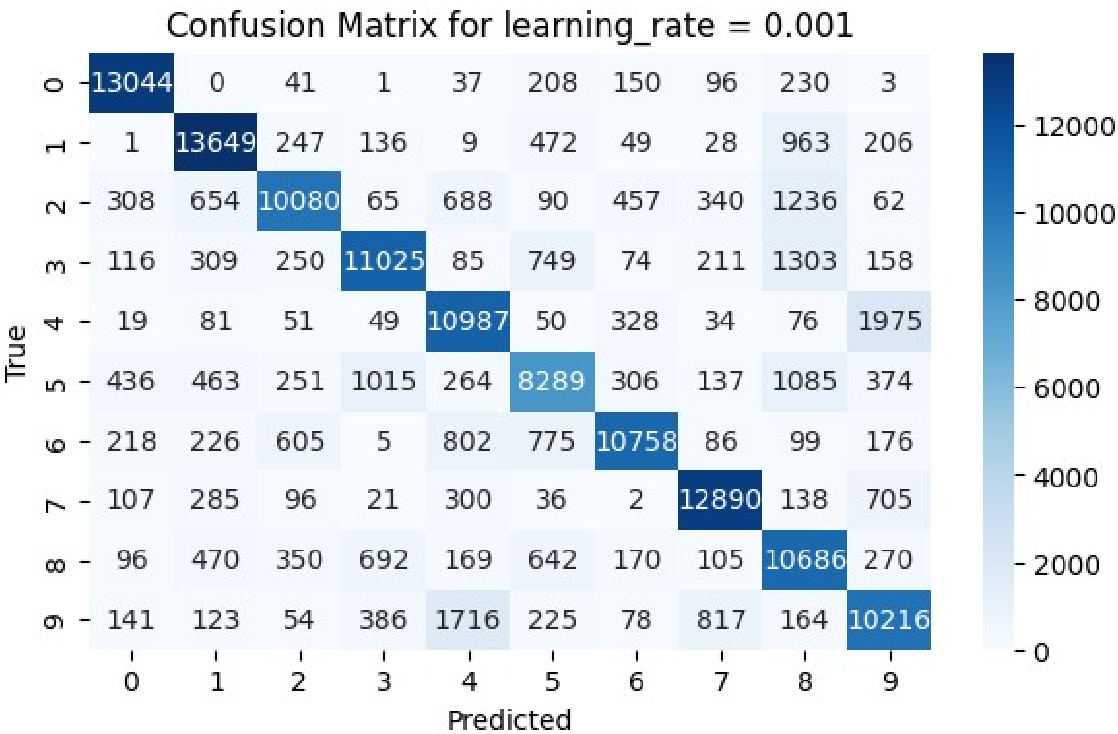
Confusion Matrix for batch_size = 256.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
0: 12558 8 39 175 14 588 272 55 70 31
1: 0 15188 127 61 1 42 12 47 266 16
2: 121 783 10660 532 400 118 654 383 269 60
3: 169 278 436 11684 36 523 50 351 673 80
4: 12 61 126 8 11469 18 285 81 446 1144
5: 350 522 244 1253 196 8778 194 183 624 276
6: 207 163 636 27 162 224 12152 12 160 7
7: 127 242 238 19 116 52 1 13191 77 517
8: 28 734 177 801 181 647 173 235 10373 301
9: 83 97 104 218 918 149 35 1262 500 10554
14000
12000
10000
8000
6000
4000
2000
0

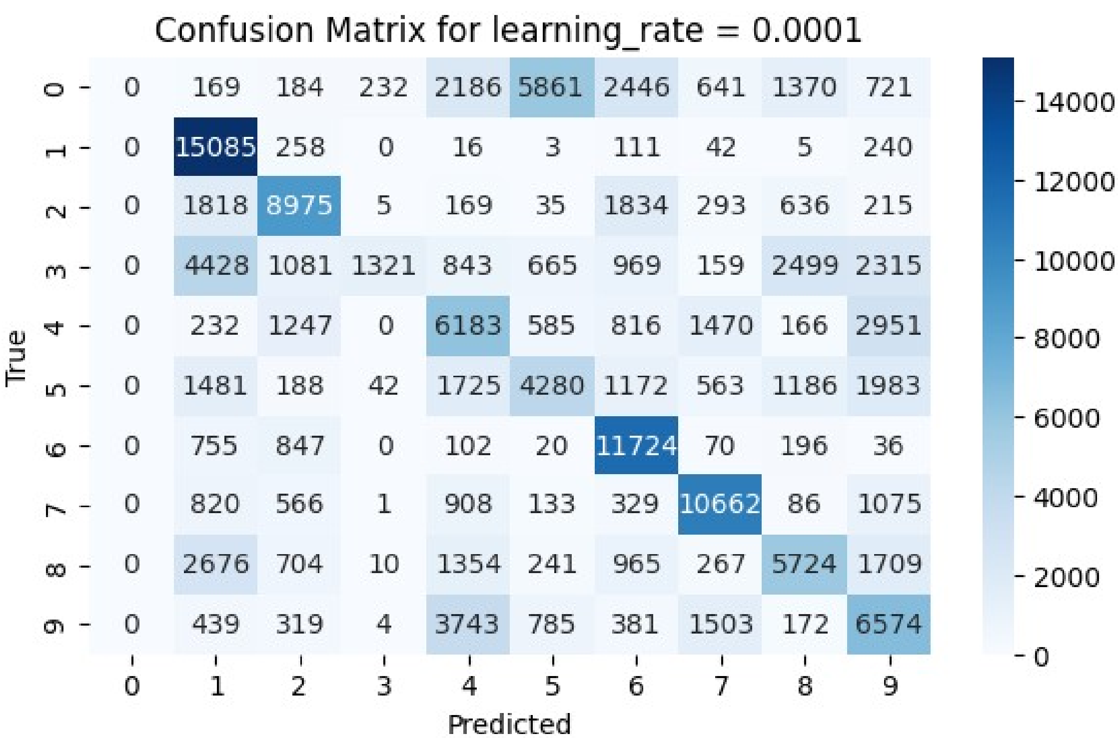

Confusion Matrix for batch_size = 500.0
13127 6 61 76 9 152 244 81 54 0
0 15339 91 105 0 59 15 37 104 10
374 796 10430 525 275 39 414 601 494 32
268 644 845 10714 36 775 57 455 255 231
189 334 27 13 8604 23 374 278 698 3110
647 633 205 966 270 8569 208 100 409 613
886 506 188 354 94 220 10836 258 407 1
142 607 165 59 146 14 8 11729 29 1681
385 1207 285 483 157 994 77 220 9431 411
230 357 71 145 972 174 51 1154 153 10613
True
0 1 2 3 4 5 6 7 8 9
Predicted
0 2000 4000 6000 8000 10000 12000 14000

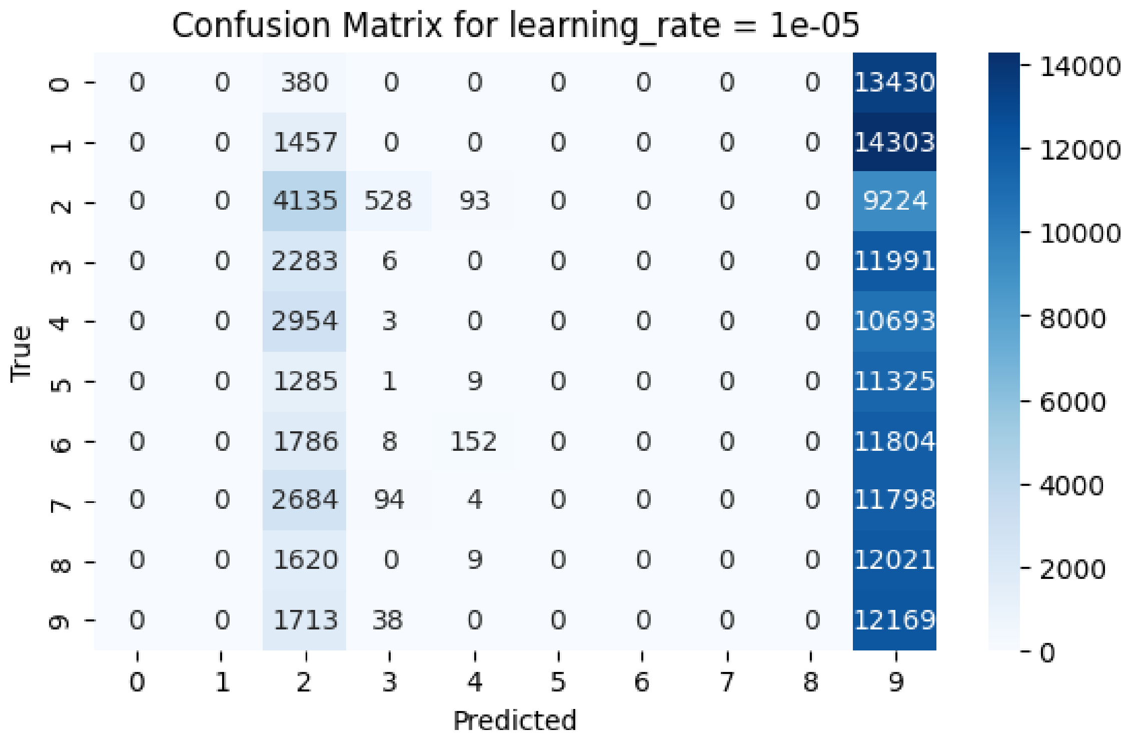

Confusion Matrix for batch_size = 1000.0
10864 18 367 106 24 27 1364 80 928 32
1 15236 64 13 0 10 154 109 138 35
552 1574 9142 8 80 0 1370 421 814 19
870 767 531 2042 30 1038 1546 261 6284 911
72 3477 820 0 2694 21 864 2160 771 2771
469 1181 145 506 279 2765 1587 186 4584 918
139 758 657 10 66 84 11962 10 63 1
42 1396 125 1 208 12 46 11284 1094 372
361 1230 88 255 43 174 558 161 10319 461
115 2237 414 51 690 41 121 2768 2036 5447
True
0 1 2 3 4 5 6 7 8 9
Predicted
0 2000 4000 6000 8000 10000 12000 14000

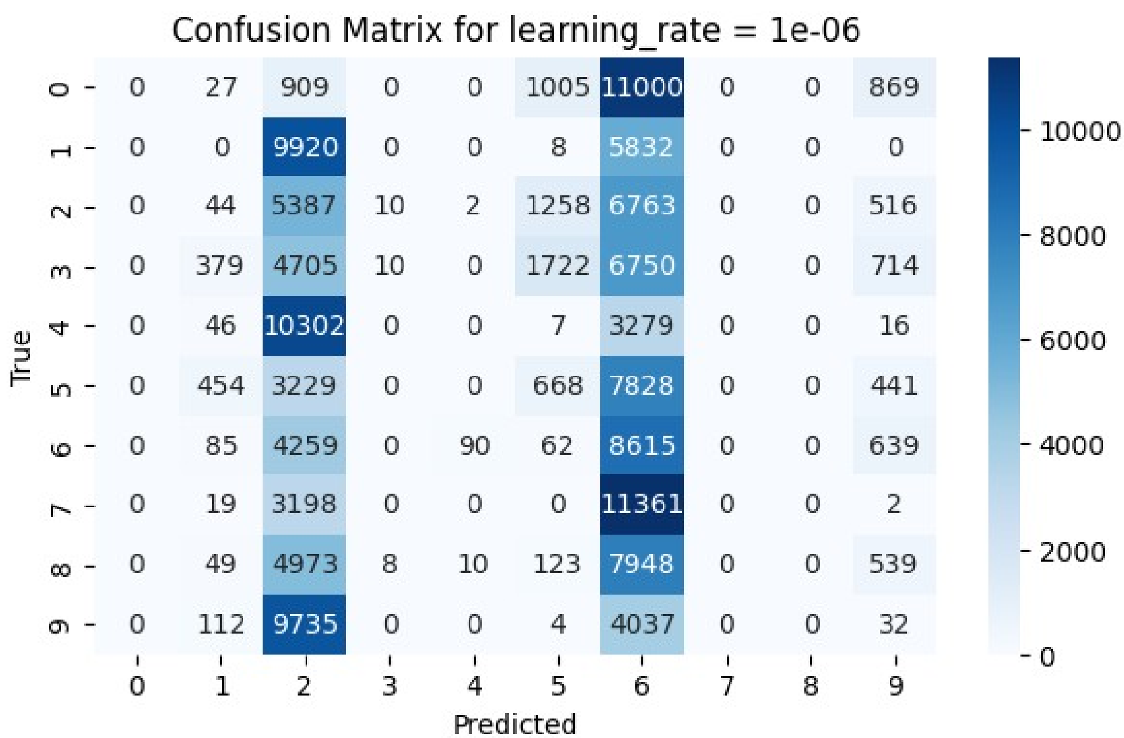

Confusion Matrix for learning_rate = 0.1
True
Predicted


Confusion Matrix for learning_rate = 0.01
True
Predicted


Confusion Matrix for learning_rate = 0.001
True
Predicted
0 1 2 3 4 5 6 7 8 9
0: 13044 0 41 1 37 208 150 96 230 3
1: 1 13649 247 136 9 472 49 28 963 206
2: 308 654 10080 65 688 90 457 340 1236 62
3: 116 309 250 11025 85 749 74 211 1303 158
4: 19 81 51 49 10987 50 328 34 76 1975
5: 436 463 251 1015 264 8289 306 137 1085 374
6: 218 226 605 5 802 775 10758 86 99 176
7: 107 285 96 21 300 36 2 12890 138 705
8: 96 470 350 692 169 642 170 105 10686 270
9: 141 123 54 386 1716 225 78 817 164 10216
0
2000
4000
6000
8000
10000
12000


Confusion Matrix for learning_rate = 0.0001
True
Predicted
0 1 2 3 4 5 6 7 8 9
0: 0 169 184 232 2186 5861 2446 641 1370 721
1: 0 15085 258 0 16 3 111 42 5 240
2: 0 1818 8975 5 169 35 1834 293 636 215
3: 0 4428 1081 1321 843 665 969 159 2499 2315
4: 0 232 1247 0 6183 585 816 1470 166 2951
5: 0 1481 188 42 1725 4280 1172 563 1186 1983
6: 0 755 847 0 102 20 11724 70 196 36
7: 0 820 566 1 908 133 329 10662 86 1075
8: 0 2676 704 10 1354 241 965 267 5724 1709
9: 0 439 319 4 3743 785 381 1503 172 6574
0
2000
4000
6000
8000
10000
12000
14000



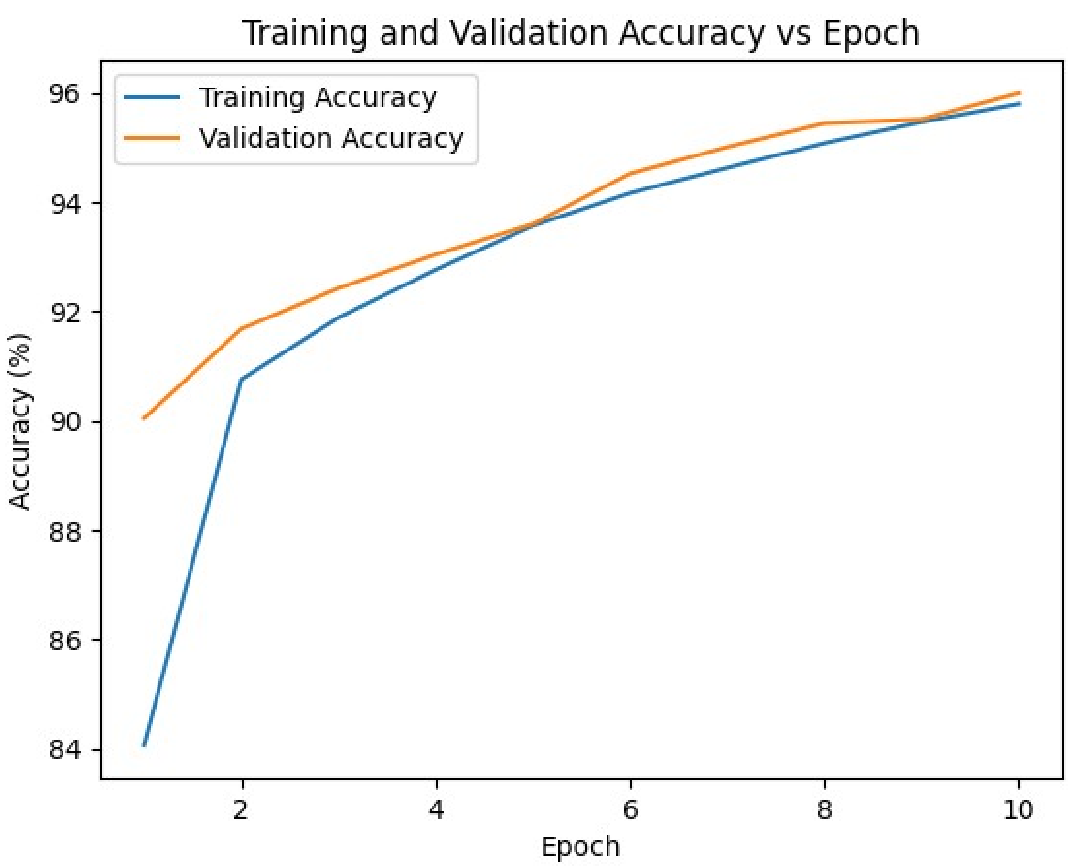


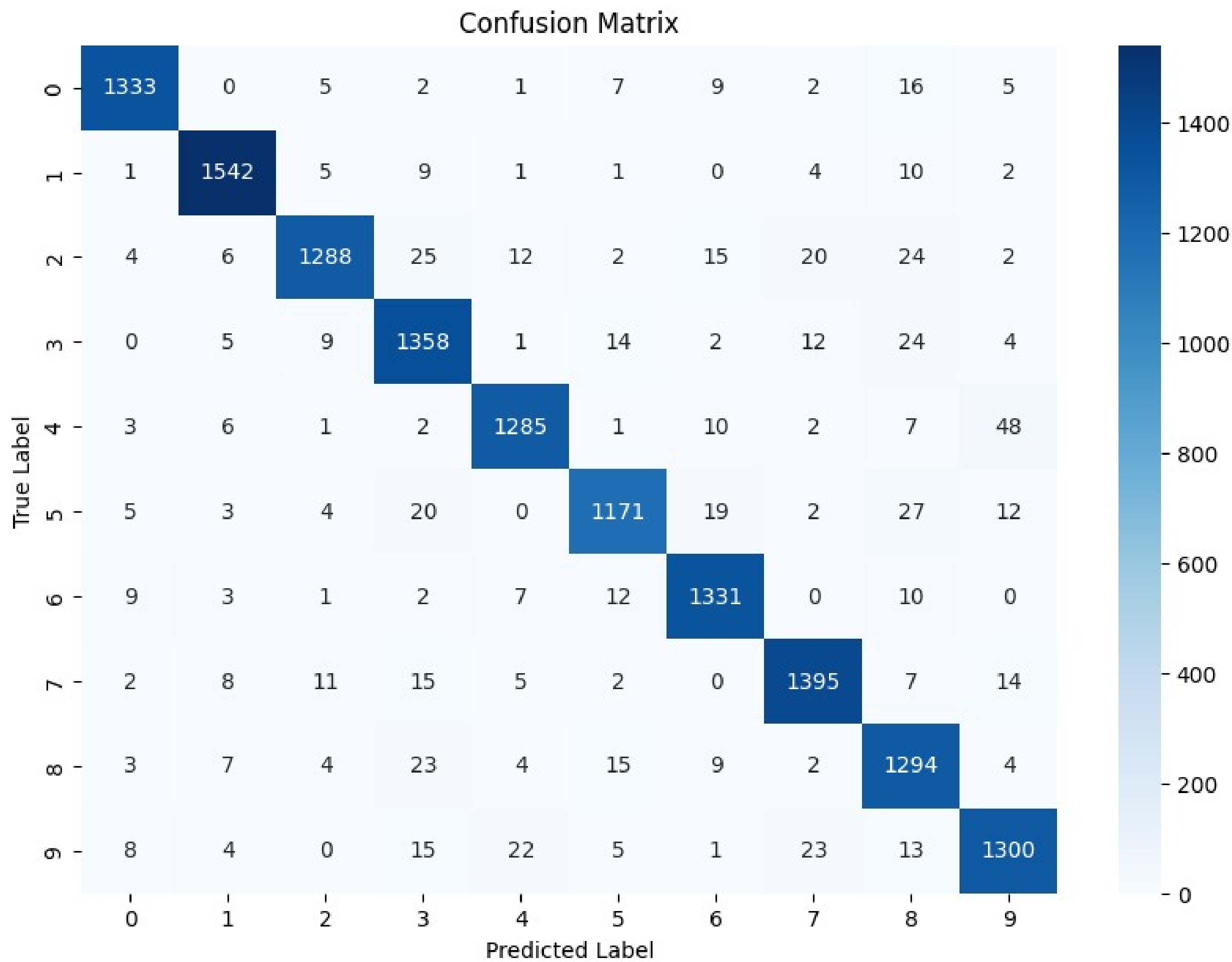
now we inspect the pool for the combination of parameters with the best accuracy, retrain the model using these parameters and finally verify on the test set.

```
# 1. Select the best parameters based on validation accuracy
def select_best_params(results):
    best_result = max(results, key=lambda x: x["val_accuracy"])  #
Find the best validation accuracy
    best_params = best_result["param"], best_result["value"]  #
Extract the parameter name and value
    print(f"Best Parameter: {best_params[0]} = {best_params[1]}")
    return best_params, best_result

best_params, best_result = select_best_params(results)
print(best_params)

# 2. Train the final model using the best parameters on combined train
+ validation data
combined_train_data = torch.utils.data.ConcatDataset([train_data,
val_data])
combined_train_loader = DataLoader(combined_train_data,
batch_size=default_params["batch_size"], shuffle=True)

# Reinitialize the model with the best hyperparameters
if best_params[0] == "hidden_layers":
    default_params["hidden_layers"] = best_params[1]
elif best_params[0] == "hidden_size":
    default_params["hidden_size"] = best_params[1]  # Use the value,
not the name
elif best_params[0] == "batch_size":
    default_params["batch_size"] = best_params[1]  # Correct this to
use the value
elif best_params[0] == "learning_rate":
    default_params["learning_rate"] = best_params[1]  # Correct this
to use the value

# Create and train the model
final_model = Neural_Network_1_hidden_layer(
    input_size=28*28,
    hidden_size=default_params["hidden_size"],
    num_classes=10
).to(device)

final_optimizer = optim.SGD(final_model.parameters(),
lr=default_params["learning_rate"])
final_criterion = nn.CrossEntropyLoss()

# Train the model on combined data
_, _, train_accs,val_accs,_ ,_ = train_model(
    final_model, combined_train_loader, val_loader, final_criterion,
final_optimizer, num_epochs=10
)
```

```
Best Parameter: hidden_size = 50
('hidden_size', 50)
Epoch [1/10], Train Loss: 0.6035, Train Accuracy: 84.06%, Validation
Loss: 0.3581, Validation Accuracy: 90.04%
Epoch [2/10], Train Loss: 0.3235, Train Accuracy: 90.75%, Validation
Loss: 0.2958, Validation Accuracy: 91.68%
Epoch [3/10], Train Loss: 0.2814, Train Accuracy: 91.88%, Validation
Loss: 0.2654, Validation Accuracy: 92.42%
Epoch [4/10], Train Loss: 0.2513, Train Accuracy: 92.76%, Validation
Loss: 0.2376, Validation Accuracy: 93.04%
Epoch [5/10], Train Loss: 0.2249, Train Accuracy: 93.56%, Validation
Loss: 0.2168, Validation Accuracy: 93.59%
Epoch [6/10], Train Loss: 0.2036, Train Accuracy: 94.16%, Validation
Loss: 0.1931, Validation Accuracy: 94.51%
Epoch [7/10], Train Loss: 0.1862, Train Accuracy: 94.62%, Validation
Loss: 0.1788, Validation Accuracy: 95.00%
Epoch [8/10], Train Loss: 0.1713, Train Accuracy: 95.07%, Validation
Loss: 0.1622, Validation Accuracy: 95.44%
Epoch [9/10], Train Loss: 0.1590, Train Accuracy: 95.46%, Validation
Loss: 0.1598, Validation Accuracy: 95.51%
Epoch [10/10], Train Loss: 0.1488, Train Accuracy: 95.79%, Validation
Loss: 0.1437, Validation Accuracy: 95.99%

def evaluate_on_test_set(model, test_loader):
    model.eval()  # Set model to evaluation mode
    correct_test = 0
    total_test = 0
    y_true = []
    y_pred = []

    with torch.no_grad():
        for inputs, labels in test_loader:
            inputs, labels = inputs.to(device), labels.to(device)

            outputs = model(inputs)
            _, predicted = torch.max(outputs.data, 1)
            total_test += labels.size(0)
            correct_test += (predicted == labels).sum().item()

            y_true.extend(labels.cpu().numpy())
            y_pred.extend(predicted.cpu().numpy())

    test_acc = 100 * correct_test / total_test
    print(f'Test Accuracy: {test_acc:.2f}%')

    return y_true, y_pred, test_acc

# Evaluate on the test set
y_true, y_pred, test_acc = evaluate_on_test_set(final_model,
test_loader)
```

```
Test Accuracy: 94.98%

# Plot the accuracies for training and validation
epochs = list(range(1, 11))
plt.plot(epochs,train_accs, label="Training Accuracy")
plt.plot(epochs,val_accs, label="Validation Accuracy")
plt.xlabel("Epoch")
plt.ylabel("Accuracy (%)")
plt.title("Training and Validation Accuracy vs Epoch")
plt.legend()
plt.show()

# Plot confusion matrix
plot_confusion_matrix(y_true, y_pred)

# Optionally, print the test accuracy
print(f"Test Accuracy: {test_acc:.2f}%")
```






```
Test Accuracy: 94.98%
```

Bonus (CNN)

we will adjust the previous code and repeat the process for convoltional Neural Networks and study their features closely.

- notice that we do not need to transform the images when using CNN

```
# Load the MNIST dataset
train_dataset = datasets.MNIST(root='./data', train=True) #this 
structure contains data and labels
test_dataset = datasets.MNIST(root='./data', train=False)

#combine the datasets
combined_dataset=ConcatDataset([train_dataset,test_dataset])

#extract labels
train_labels=train_dataset.targets
```

```
test_labels=test_dataset.targets

# Combine labels from both train and test datasets
all_labels = torch.cat((train_labels, test_labels), dim=0)

#split into 60-40
train_idx, temp_idx = train_test_split(
    range(len(combined_dataset)), test_size=0.4, stratify=all_labels,
random_state=42) # stratify 3lshan not to get skewed data


#split again 20-20
# Split temp (40%) into validation (20%) and test (20%)
val_idx, test_idx = train_test_split(
    temp_idx, test_size=0.5, stratify=all_labels[temp_idx],
random_state=42) # returns indices


# Create Subset objects for train, validation, and test sets
train_data = Subset(combined_dataset, train_idx)
val_data = Subset(combined_dataset, val_idx)
test_data = Subset(combined_dataset, test_idx)


##recreate dataset w inheirt combatible structure with data loader
# Create DataLoader objects
batch_size = 32
train_loader = DataLoader(train_data, batch_size=batch_size,
shuffle=True)
val_loader = DataLoader(val_data, batch_size=batch_size,
shuffle=False)
test_loader = DataLoader(test_data, batch_size=batch_size,
shuffle=False)

# Print split sizes
print(f"Training set size: {len(train_data)}")
print(f"Validation set size: {len(val_data)}")
print(f"Test set size: {len(test_data)}")
print("Data preparation complete!")
```

```
Training set size: 42000
Validation set size: 14000
Test set size: 14000
Data preparation complete!
```

```
import torch
import torch.nn as nn
import torch.optim as optim
from torch.utils.data import DataLoader
from torchvision import datasets, transforms
```

```
# Default hyperparameters
default_params_cnn = {
    "hidden_layers": 5,  # Number of convolutional layers
    "hidden_size": 10,   # Number of filters per layer
    "batch_size": 32,    # Batch size
    "learning_rate": 0.01,
    "dropout_prob": 0.5  # Dropout probability
}

# Hyperparameter ranges for tuning
param_ranges_cnn = {
    "hidden_layers": [5, 7, 9],
    "hidden_size": [30, 50, 70],
    "batch_size": [128, 256, 512],
    "learning_rate": [0.01, 0.001, 0.0001],
    "dropout_prob": [0.25, 0.5, 0.75]
}

# Device configuration
device = torch.device("cuda" if torch.cuda.is_available() else "cpu")

# Data preparation
transform = transforms.Compose([
    transforms.ToTensor(),
    transforms.Normalize((0.5,), (0.5,))
])

train_data = datasets.MNIST(root="data", train=True, download=True,
transform=transform)
val_data = datasets.MNIST(root="data", train=False, download=True,
transform=transform)


class ConvNeuralNetwork(nn.Module):
    def __init__(self, input_channels, hidden_layers, hidden_size,
num_classes, dropout_prob):
        super(ConvNeuralNetwork, self).__init__()

        layers = []

        # First convolutional layer
        layers.append(nn.Conv2d(input_channels, hidden_size,
kernel_size=3, padding=1))  # 3x3 kernel(filter)
        layers.append(nn.ReLU())
        layers.append(nn.LayerNorm([hidden_size, 28, 28]))
        layers.append(nn.Dropout(dropout_prob))

        # Additional convolutional layers
        for i in range(1, hidden_layers):
```

```
            layers.append(nn.Conv2d(hidden_size, hidden_size,
kernel_size=3, padding=1))
            layers.append(nn.ReLU())
            layers.append(nn.LayerNorm([hidden_size, 28, 28]))
            layers.append(nn.Dropout(dropout_prob))

        # Pooling layer
        layers.append(nn.MaxPool2d(kernel_size=2, stride=2))  #
Reduces dimensions to 14x14

        # Flatten layer for the fully connected layer
        self.flatten = nn.Flatten()

        # Fully connected layer
        fc_input_size = hidden_size * 14 * 14  # After pooling
        self.fc = nn.Linear(fc_input_size, num_classes)

        self.network = nn.Sequential(*layers)

    def forward(self, x):
        x = self.network(x)
        x = self.flatten(x)
        x = self.fc(x)
        return x


def train_model(model, train_loader, val_loader, criterion, optimizer,
num_epochs=10):
    train_losses, val_losses = [], []
    train_accuracies, val_accuracies = [], []

    for epoch in range(num_epochs):
        # Training phase
        model.train()
        correct, total, train_loss = 0, 0, 0
        for inputs, labels in train_loader:
            inputs, labels = inputs.to(device), labels.to(device)
            optimizer.zero_grad()

            outputs = model(inputs)
            loss = criterion(outputs, labels)
            loss.backward()
            optimizer.step()

            train_loss += loss.item()
            _, predicted = torch.max(outputs, 1)
            correct += (predicted == labels).sum().item()
            total += labels.size(0)

        train_losses.append(train_loss / len(train_loader))
```

```
        train_accuracies.append(correct / total)

        # Validation phase
        model.eval()
        correct, total, val_loss = 0, 0, 0
        y_true, y_pred = [], []
        with torch.no_grad():
            for inputs, labels in val_loader:
                inputs, labels = inputs.to(device), labels.to(device)
                outputs = model(inputs)
                loss = criterion(outputs, labels)
                val_loss += loss.item()
                _, predicted = torch.max(outputs, 1)
                correct += (predicted == labels).sum().item()
                total += labels.size(0)
                y_true.extend(labels.cpu().numpy())
                y_pred.extend(predicted.cpu().numpy())

        val_losses.append(val_loss / len(val_loader))
        val_accuracies.append(correct / total)

        print(f"Epoch {epoch + 1}/{num_epochs} - "
              f"Train Loss: {train_losses[-1]:.4f}, Train Accuracy:
{train_accuracies[-1]:.4f} - "
              f"Val Loss: {val_losses[-1]:.4f}, Val Accuracy:
{val_accuracies[-1]:.4f}")

    return train_losses, val_losses, train_accuracies, val_accuracies,
y_true, y_pred


def tune_hyperparameters(default_params, param_ranges, num_epochs=10):
    results = []

    # Iterate over each parameter
    for param, values in param_ranges.items():
        for value in values:
            # Update the parameter value
            params = default_params.copy()
            params[param] = value

            # Update DataLoader if batch_size changes
            batch_size = params["batch_size"]
            train_loader = DataLoader(train_data,
batch_size=batch_size, shuffle=True)
            val_loader = DataLoader(val_data, batch_size=batch_size,
shuffle=False)

            # Build the model
            model = ConvNeuralNetwork(
```

```
                input_channels=1,  # MNIST has 1 channel
                hidden_layers=params["hidden_layers"],
                hidden_size=params["hidden_size"],
                num_classes=10,
                dropout_prob=params["dropout_prob"]
            ).to(device)

            # Define optimizer with new learning rate
            optimizer = optim.Adam(model.parameters(),
lr=params["learning_rate"])
            criterion = nn.CrossEntropyLoss()

            # Train the model
            train_losses, val_losses, train_accuracies,
val_accuracies, y_true, y_pred = train_model(
                model, train_loader, val_loader, criterion, optimizer,
num_epochs=num_epochs
            )

            # Record results
            results.append({
                "param": param,
                "value": value,
                "train_accuracy": train_accuracies[-1],
                "val_accuracy": val_accuracies[-1],
                "train_loss": train_losses[-1],
                "val_loss": val_losses[-1],
                "y_true": y_true,
                "y_pred": y_pred
            })

            print(f"Completed training for {param} = {value}")

    return results


# Example usage
results = tune_hyperparameters(default_params_cnn, param_ranges_cnn,
num_epochs=5)
```

```
Epoch 1/5 - Train Loss: 0.6286, Train Accuracy: 0.8488 - Val Loss:
0.3645, Val Accuracy: 0.8917
Epoch 2/5 - Train Loss: 0.2694, Train Accuracy: 0.9290 - Val Loss:
0.2912, Val Accuracy: 0.9140
Epoch 3/5 - Train Loss: 0.2581, Train Accuracy: 0.9356 - Val Loss:
1.0703, Val Accuracy: 0.7722
Epoch 4/5 - Train Loss: 0.2719, Train Accuracy: 0.9366 - Val Loss:
0.6632, Val Accuracy: 0.8681
Epoch 5/5 - Train Loss: 0.2767, Train Accuracy: 0.9394 - Val Loss:
0.6576, Val Accuracy: 0.8632
```

```
Completed training for hidden_layers = 5
Epoch 1/5 - Train Loss: 0.5572, Train Accuracy: 0.8637 - Val Loss:
1.8260, Val Accuracy: 0.4912
Epoch 2/5 - Train Loss: 0.2922, Train Accuracy: 0.9168 - Val Loss:
1.0553, Val Accuracy: 0.7176
Epoch 3/5 - Train Loss: 0.2916, Train Accuracy: 0.9214 - Val Loss:
0.4345, Val Accuracy: 0.8793
Epoch 4/5 - Train Loss: 0.2892, Train Accuracy: 0.9253 - Val Loss:
0.3959, Val Accuracy: 0.9011
Epoch 5/5 - Train Loss: 0.2826, Train Accuracy: 0.9292 - Val Loss:
0.2874, Val Accuracy: 0.9317
Completed training for hidden_layers = 7
Epoch 1/5 - Train Loss: 0.6660, Train Accuracy: 0.8247 - Val Loss:
0.4822, Val Accuracy: 0.8478
Epoch 2/5 - Train Loss: 0.3209, Train Accuracy: 0.9074 - Val Loss:
0.3325, Val Accuracy: 0.9049
Epoch 3/5 - Train Loss: 0.2915, Train Accuracy: 0.9190 - Val Loss:
0.3287, Val Accuracy: 0.9201
Epoch 4/5 - Train Loss: 0.2958, Train Accuracy: 0.9228 - Val Loss:
0.3433, Val Accuracy: 0.8984
Epoch 5/5 - Train Loss: 0.2824, Train Accuracy: 0.9289 - Val Loss:
0.3132, Val Accuracy: 0.9136
Completed training for hidden_layers = 9
Epoch 1/5 - Train Loss: 0.7969, Train Accuracy: 0.8651 - Val Loss:
4.9081, Val Accuracy: 0.2901
Epoch 2/5 - Train Loss: 0.3784, Train Accuracy: 0.9261 - Val Loss:
3.0263, Val Accuracy: 0.7134
Epoch 3/5 - Train Loss: 0.4684, Train Accuracy: 0.9377 - Val Loss:
0.8222, Val Accuracy: 0.8899
Epoch 4/5 - Train Loss: 0.5289, Train Accuracy: 0.9456 - Val Loss:
0.6941, Val Accuracy: 0.9365
Epoch 5/5 - Train Loss: 0.6020, Train Accuracy: 0.9523 - Val Loss:
2.3588, Val Accuracy: 0.8538
Completed training for hidden_size = 30
Epoch 1/5 - Train Loss: 1.3207, Train Accuracy: 0.8887 - Val Loss:
2.1529, Val Accuracy: 0.7586
Epoch 2/5 - Train Loss: 0.6117, Train Accuracy: 0.9394 - Val Loss:
0.9601, Val Accuracy: 0.9368
Epoch 3/5 - Train Loss: 0.7775, Train Accuracy: 0.9505 - Val Loss:
1.7333, Val Accuracy: 0.8878
Epoch 4/5 - Train Loss: 0.8765, Train Accuracy: 0.9589 - Val Loss:
2.3877, Val Accuracy: 0.9195
Epoch 5/5 - Train Loss: 1.0356, Train Accuracy: 0.9642 - Val Loss:
1.0668, Val Accuracy: 0.9639
Completed training for hidden_size = 50
Epoch 1/5 - Train Loss: 1.5462, Train Accuracy: 0.8262 - Val Loss:
30.3408, Val Accuracy: 0.1994
Epoch 2/5 - Train Loss: 0.8332, Train Accuracy: 0.8967 - Val Loss:
19.1903, Val Accuracy: 0.3361
```

```
Epoch 3/5 - Train Loss: 1.0777, Train Accuracy: 0.9205 - Val Loss:
11.8448, Val Accuracy: 0.5724
Epoch 4/5 - Train Loss: 1.3010, Train Accuracy: 0.9346 - Val Loss:
19.3208, Val Accuracy: 0.5599
Epoch 5/5 - Train Loss: 1.4493, Train Accuracy: 0.9435 - Val Loss:
23.3425, Val Accuracy: 0.5950
Completed training for hidden_size = 70
Epoch 1/5 - Train Loss: 0.7810, Train Accuracy: 0.8201 - Val Loss:
1.8387, Val Accuracy: 0.4948
Epoch 2/5 - Train Loss: 0.2548, Train Accuracy: 0.9252 - Val Loss:
0.4694, Val Accuracy: 0.8480
Epoch 3/5 - Train Loss: 0.1823, Train Accuracy: 0.9465 - Val Loss:
0.2784, Val Accuracy: 0.9070
Epoch 4/5 - Train Loss: 0.1542, Train Accuracy: 0.9556 - Val Loss:
0.1537, Val Accuracy: 0.9507
Epoch 5/5 - Train Loss: 0.1430, Train Accuracy: 0.9573 - Val Loss:
0.1159, Val Accuracy: 0.9637
Completed training for batch_size = 128
Epoch 1/5 - Train Loss: 1.4737, Train Accuracy: 0.7449 - Val Loss:
5.6710, Val Accuracy: 0.3106
Epoch 2/5 - Train Loss: 0.4352, Train Accuracy: 0.8661 - Val Loss:
2.4213, Val Accuracy: 0.4797
Epoch 3/5 - Train Loss: 0.3141, Train Accuracy: 0.9019 - Val Loss:
1.8878, Val Accuracy: 0.5518
Epoch 4/5 - Train Loss: 0.2500, Train Accuracy: 0.9230 - Val Loss:
2.1881, Val Accuracy: 0.5091
Epoch 5/5 - Train Loss: 0.2089, Train Accuracy: 0.9357 - Val Loss:
1.2663, Val Accuracy: 0.6468
Completed training for batch_size = 256
Epoch 1/5 - Train Loss: 2.0295, Train Accuracy: 0.6843 - Val Loss:
3.6860, Val Accuracy: 0.4168
Epoch 2/5 - Train Loss: 0.5258, Train Accuracy: 0.8383 - Val Loss:
2.7441, Val Accuracy: 0.4734
Epoch 3/5 - Train Loss: 0.4646, Train Accuracy: 0.8554 - Val Loss:
2.0511, Val Accuracy: 0.5145
Epoch 4/5 - Train Loss: 0.3481, Train Accuracy: 0.8916 - Val Loss:
1.1292, Val Accuracy: 0.6891
Epoch 5/5 - Train Loss: 0.2614, Train Accuracy: 0.9219 - Val Loss:
0.7475, Val Accuracy: 0.7613
Completed training for batch_size = 512
Epoch 1/5 - Train Loss: 0.5938, Train Accuracy: 0.8592 - Val Loss:
0.4149, Val Accuracy: 0.8692
Epoch 2/5 - Train Loss: 0.2716, Train Accuracy: 0.9252 - Val Loss:
0.1999, Val Accuracy: 0.9441
Epoch 3/5 - Train Loss: 0.2781, Train Accuracy: 0.9304 - Val Loss:
0.5721, Val Accuracy: 0.8686
Epoch 4/5 - Train Loss: 0.2720, Train Accuracy: 0.9355 - Val Loss:
0.7362, Val Accuracy: 0.8507
Epoch 5/5 - Train Loss: 0.2852, Train Accuracy: 0.9384 - Val Loss:
```

```
0.6331, Val Accuracy: 0.8785
Completed training for learning_rate = 0.01
Epoch 1/5 - Train Loss: 0.4270, Train Accuracy: 0.8684 - Val Loss:
0.1632, Val Accuracy: 0.9499
Epoch 2/5 - Train Loss: 0.1981, Train Accuracy: 0.9429 - Val Loss:
0.1018, Val Accuracy: 0.9703
Epoch 3/5 - Train Loss: 0.1560, Train Accuracy: 0.9572 - Val Loss:
0.0898, Val Accuracy: 0.9734
Epoch 4/5 - Train Loss: 0.1376, Train Accuracy: 0.9621 - Val Loss:
0.0885, Val Accuracy: 0.9753
Epoch 5/5 - Train Loss: 0.1187, Train Accuracy: 0.9668 - Val Loss:
0.0706, Val Accuracy: 0.9781
Completed training for learning_rate = 0.001
Epoch 1/5 - Train Loss: 1.0787, Train Accuracy: 0.6462 - Val Loss:
0.4337, Val Accuracy: 0.8765
Epoch 2/5 - Train Loss: 0.3629, Train Accuracy: 0.8865 - Val Loss:
0.2982, Val Accuracy: 0.9088
Epoch 3/5 - Train Loss: 0.2604, Train Accuracy: 0.9189 - Val Loss:
0.2076, Val Accuracy: 0.9361
Epoch 4/5 - Train Loss: 0.2086, Train Accuracy: 0.9355 - Val Loss:
0.1822, Val Accuracy: 0.9462
Epoch 5/5 - Train Loss: 0.1730, Train Accuracy: 0.9466 - Val Loss:
0.1608, Val Accuracy: 0.9511
Completed training for learning_rate = 0.0001
Epoch 1/5 - Train Loss: 0.4303, Train Accuracy: 0.9040 - Val Loss:
0.1624, Val Accuracy: 0.9519
Epoch 2/5 - Train Loss: 0.1589, Train Accuracy: 0.9575 - Val Loss:
0.1885, Val Accuracy: 0.9544
Epoch 3/5 - Train Loss: 0.1715, Train Accuracy: 0.9598 - Val Loss:
0.2638, Val Accuracy: 0.9492
Epoch 4/5 - Train Loss: 0.1849, Train Accuracy: 0.9624 - Val Loss:
0.1579, Val Accuracy: 0.9669
Epoch 5/5 - Train Loss: 0.1979, Train Accuracy: 0.9644 - Val Loss:
0.3136, Val Accuracy: 0.9548
Completed training for dropout_prob = 0.25
Epoch 1/5 - Train Loss: 0.6011, Train Accuracy: 0.8551 - Val Loss:
0.8950, Val Accuracy: 0.6911
Epoch 2/5 - Train Loss: 0.2787, Train Accuracy: 0.9250 - Val Loss:
0.9171, Val Accuracy: 0.7662
Epoch 3/5 - Train Loss: 0.2750, Train Accuracy: 0.9308 - Val Loss:
0.3244, Val Accuracy: 0.9098
Epoch 4/5 - Train Loss: 0.2721, Train Accuracy: 0.9338 - Val Loss:
0.3477, Val Accuracy: 0.9098
Epoch 5/5 - Train Loss: 0.2834, Train Accuracy: 0.9370 - Val Loss:
0.2573, Val Accuracy: 0.9432
Completed training for dropout_prob = 0.5
Epoch 1/5 - Train Loss: 1.2692, Train Accuracy: 0.7437 - Val Loss:
0.7023, Val Accuracy: 0.7478
Epoch 2/5 - Train Loss: 0.5890, Train Accuracy: 0.8254 - Val Loss:
```

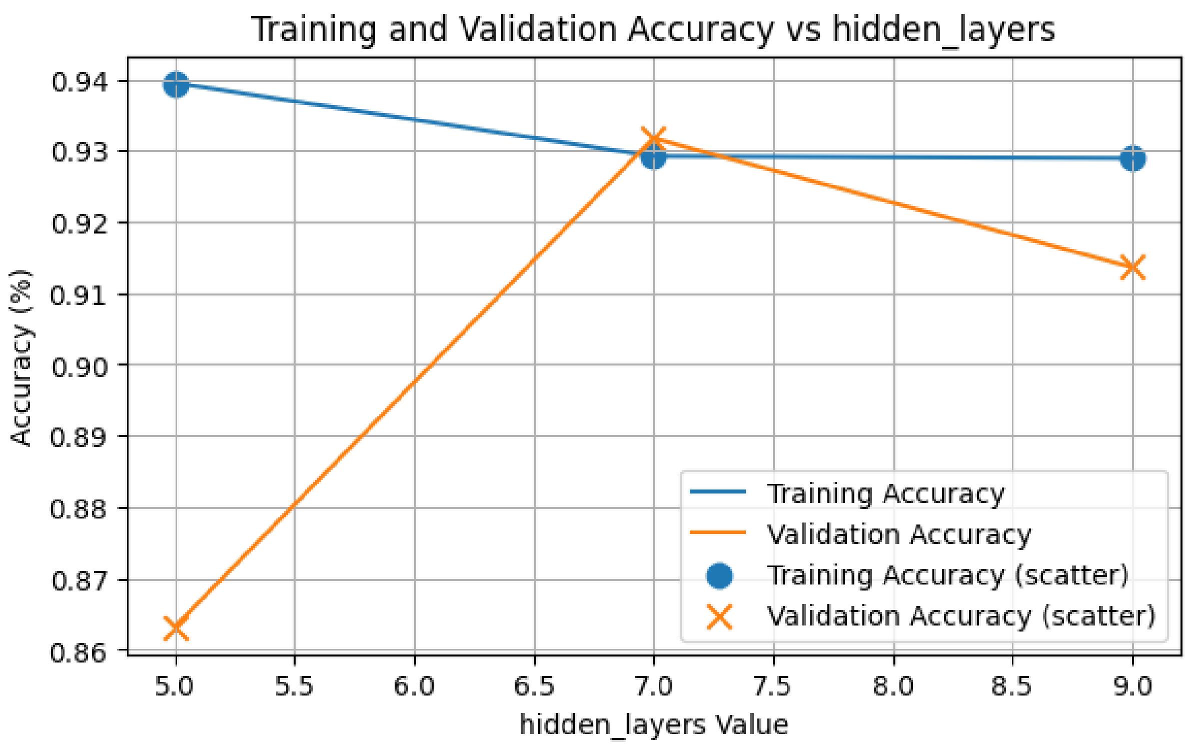
```
1.0721, Val Accuracy: 0.7369
Epoch 3/5 - Train Loss: 0.5701, Train Accuracy: 0.8323 - Val Loss: 
0.8930, Val Accuracy: 0.7472
Epoch 4/5 - Train Loss: 0.5742, Train Accuracy: 0.8328 - Val Loss: 
2.2996, Val Accuracy: 0.5820
Epoch 5/5 - Train Loss: 0.5587, Train Accuracy: 0.8400 - Val Loss: 
2.1126, Val Accuracy: 0.5805
Completed training for dropout_prob = 0.75
```

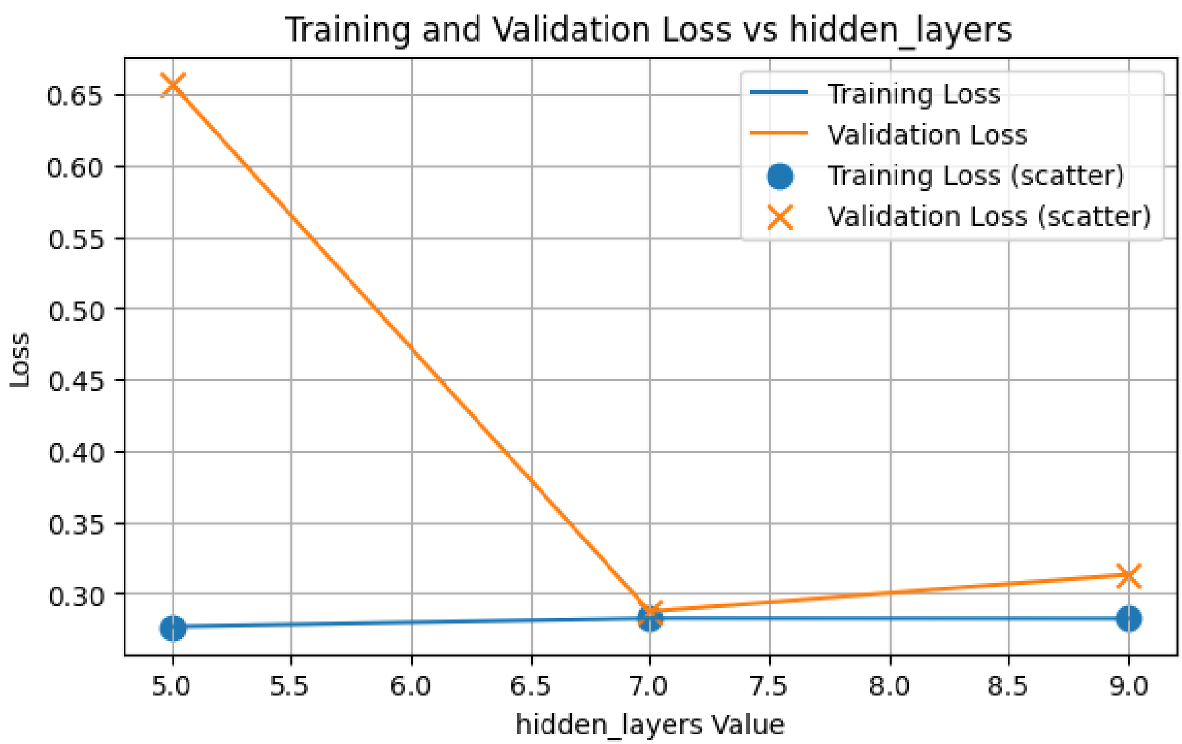
```python
# Convert the results list to a DataFrame
df = pd.DataFrame(results)

# Inspect the columns to ensure they match expected names
print("Columns in DataFrame:", df.columns)

# Verify sample rows to confirm data integrity
print(df.head())
```

```
Columns in DataFrame: Index(['param', 'value', 'train_accuracy', 
'val_accuracy', 'train_loss',
       'val_loss', 'y_true', 'y_pred'],
      dtype='object')
           param  value  train_accuracy  val_accuracy  train_loss  
val_loss  \
0  hidden_layers    5.0        0.939433        0.8632    0.276677  
0.657580   
1  hidden_layers    7.0        0.929167        0.9317    0.282560  
0.287354   
2  hidden_layers    9.0        0.928883        0.9136    0.282382  
0.313214   
3    hidden_size   30.0        0.952283        0.8538    0.601990  
2.358824   
4    hidden_size   50.0        0.964200        0.9639    1.035592  
1.066752   

                                              y_true  \
0  [7, 2, 1, 0, 4, 1, 4, 9, 5, 9, 0, 6, 9, 0, 1, ...   
1  [7, 2, 1, 0, 4, 1, 4, 9, 5, 9, 0, 6, 9, 0, 1, ...   
2  [7, 2, 1, 0, 4, 1, 4, 9, 5, 9, 0, 6, 9, 0, 1, ...   
3  [7, 2, 1, 0, 4, 1, 4, 9, 5, 9, 0, 6, 9, 0, 1, ...   
4  [7, 2, 1, 0, 4, 1, 4, 9, 5, 9, 0, 6, 9, 0, 1, ...   

                                              y_pred  
0  [7, 2, 1, 0, 4, 1, 4, 9, 6, 9, 0, 6, 9, 0, 1, ...  
1  [7, 2, 1, 0, 4, 1, 4, 9, 5, 9, 0, 6, 9, 0, 1, ...  
2  [7, 2, 1, 0, 4, 1, 4, 9, 5, 9, 0, 6, 9, 0, 1, ...  
3  [7, 1, 1, 0, 4, 1, 1, 9, 5, 9, 0, 6, 9, 0, 1, ...  
4  [7, 2, 1, 0, 4, 1, 4, 9, 5, 9, 0, 6, 9, 0, 1, ...  
```

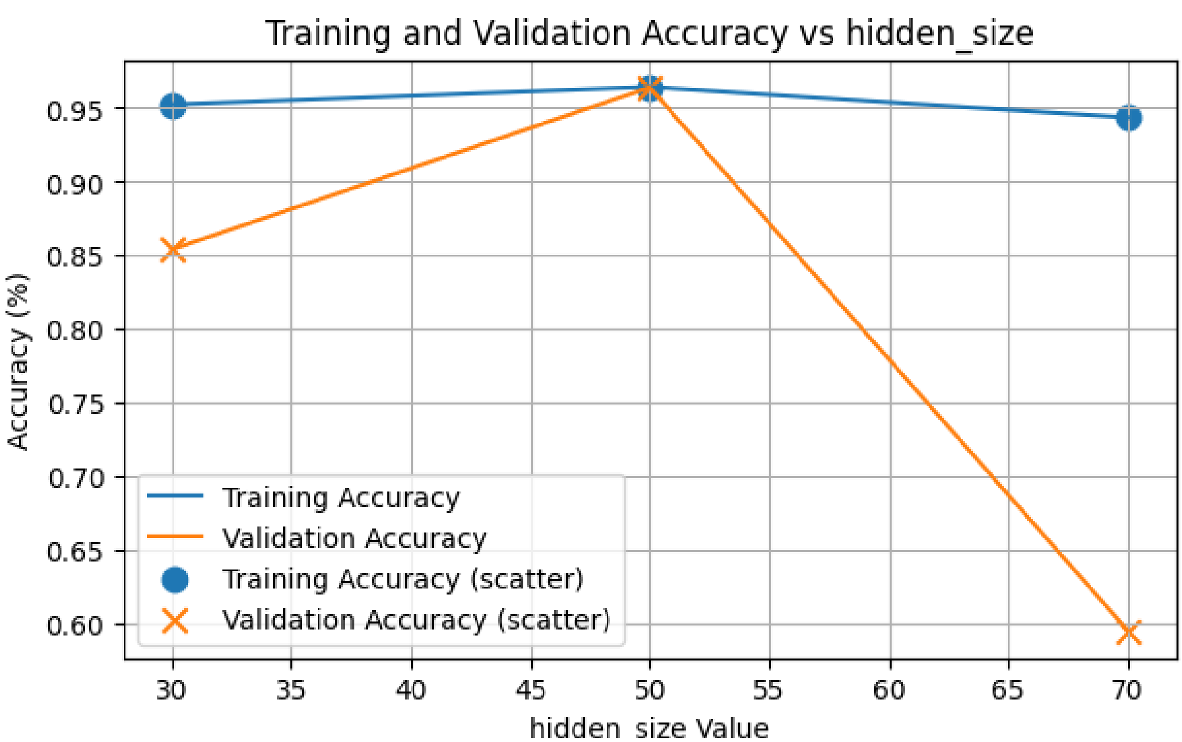
```
import matplotlib.pyplot as plt
from sklearn.metrics import confusion_matrix

# Plot Training & Validation Accuracy and Loss for each parameter
separately
unique_params = df["param"].unique()

for param in unique_params:
    # Filter the DataFrame for the current parameter
    subset = df[df["param"] == param]

    print(f"--------------------------------------------- Accuracy and
Loss for {param} -------------------------------------------- ")

    # Plot Training and Validation Accuracy on the same graph
    plt.figure(figsize=(7, 4))
    plt.plot(subset["value"], subset["train_accuracy"], linestyle='-',
label="Training Accuracy")
    plt.plot(subset["value"], subset["val_accuracy"], linestyle='-',
label="Validation Accuracy")
    plt.scatter(subset["value"], subset["train_accuracy"], marker='o',
s=80, label="Training Accuracy (scatter)")
    plt.scatter(subset["value"], subset["val_accuracy"], marker='x',
s=80, label="Validation Accuracy (scatter)")
    plt.title(f"Training and Validation Accuracy vs {param}")
    plt.xlabel(f"{param} Value")
    plt.ylabel("Accuracy (%)")
    plt.grid()
    plt.legend()
    plt.show()

    # Plot Training and Validation Loss on the same graph
    plt.figure(figsize=(7, 4))
    plt.plot(subset["value"], subset["train_loss"], linestyle='-',
label="Training Loss")
    plt.plot(subset["value"], subset["val_loss"], linestyle='-',
label="Validation Loss")
    plt.scatter(subset["value"], subset["train_loss"], marker='o',
s=80, label="Training Loss (scatter)")
    plt.scatter(subset["value"], subset["val_loss"], marker='x', s=80,
label="Validation Loss (scatter)")
    plt.title(f"Training and Validation Loss vs {param}")
    plt.xlabel(f"{param} Value")
    plt.ylabel("Loss")
    plt.grid()
    plt.legend()
    plt.show()

print(f"--------------------------------------------- Confusion Matrix
for {param} -------------------------------------------- ")
```

```
# Plot confusion matrix for each trained model
def plot_confusion_matrix(y_true, y_pred, param, value):
    cm = confusion_matrix(y_true, y_pred)
    plt.figure(figsize=(7, 4))
    sns.heatmap(cm, annot=True, fmt="d", cmap="Blues",
xticklabels=range(10), yticklabels=range(10))
    plt.title(f'Confusion Matrix for {param} = {value}')
    plt.xlabel('Predicted')
    plt.ylabel('True')
    plt.show()

# Generate confusion matrices for each parameter and value
for idx, row in df.iterrows():
    plot_confusion_matrix(row["y_true"], row["y_pred"], row["param"],
row["value"])

--------------------------------------------- Accuracy and Loss for
hidden_layers ---------------------------------------------
```

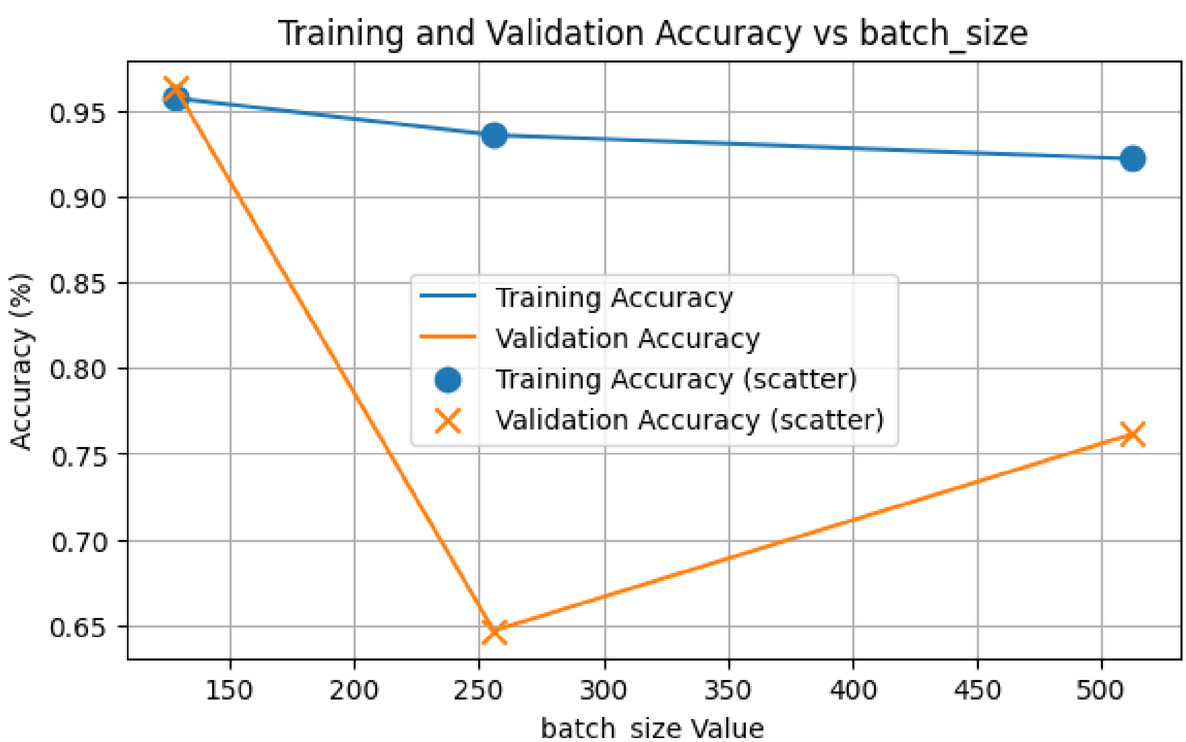


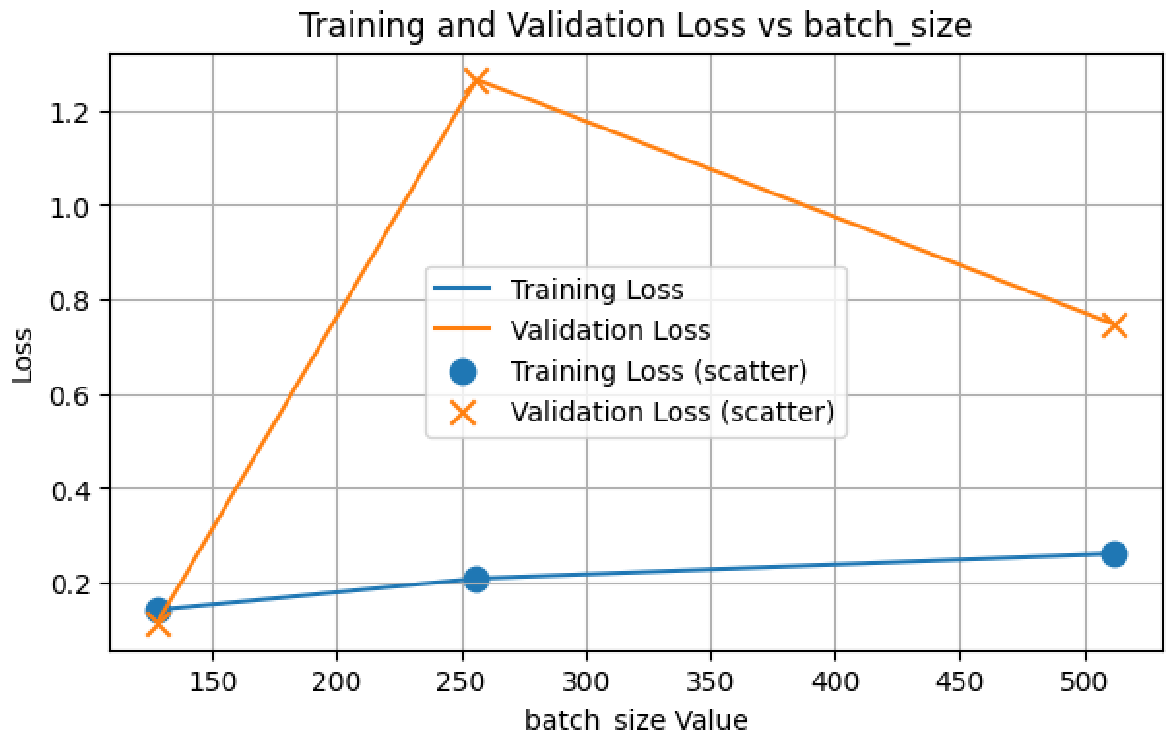



```
---------------------------------------- Accuracy and Loss for hidden_size ----------------------------------------
```

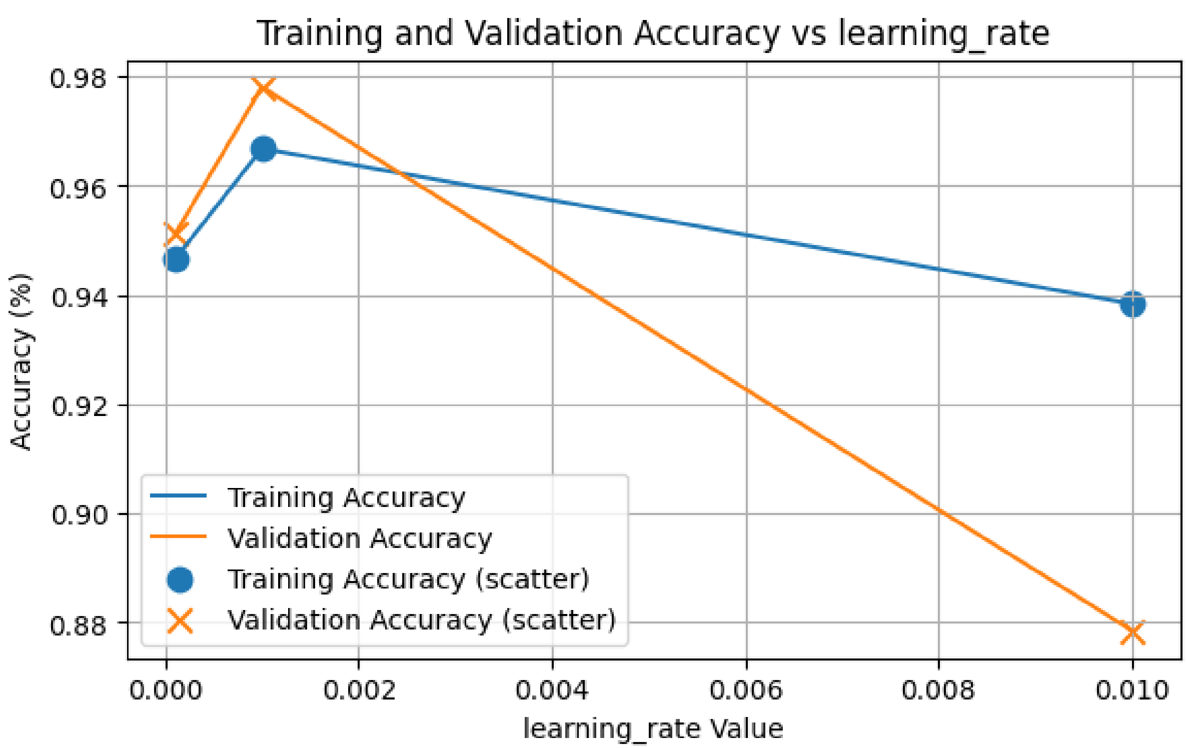


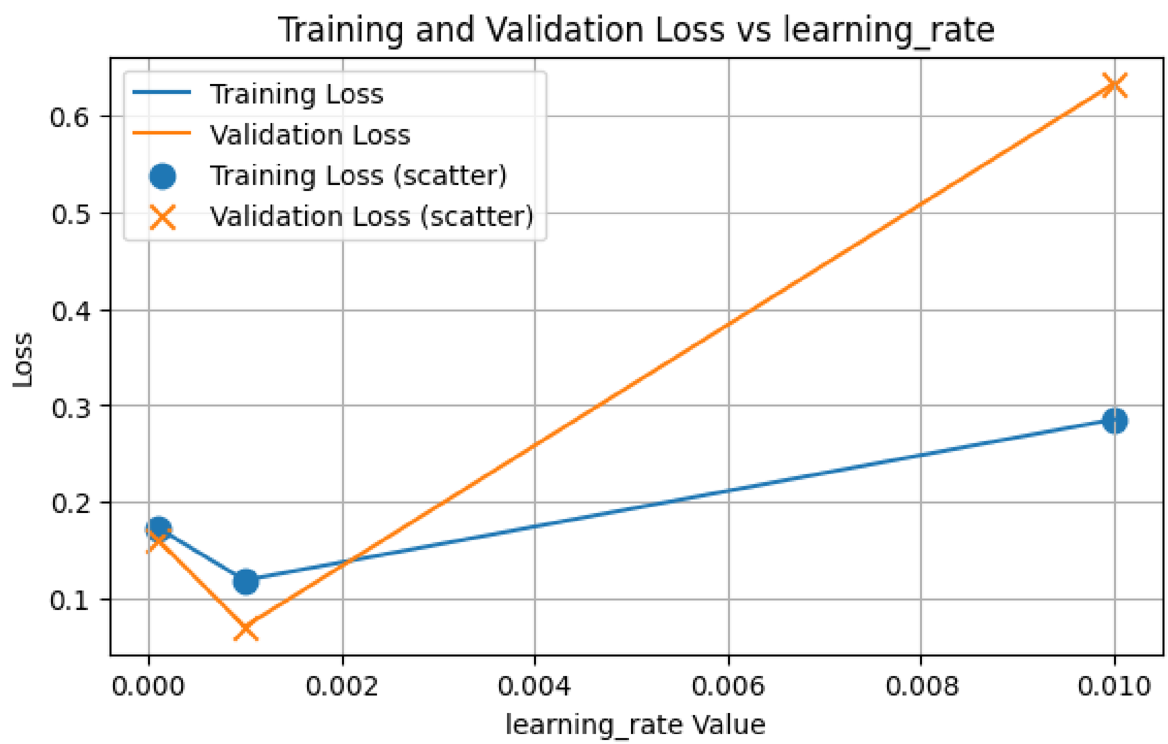

```
---------------------------------------- Accuracy and Loss for
batch_size ----------------------------------------
```



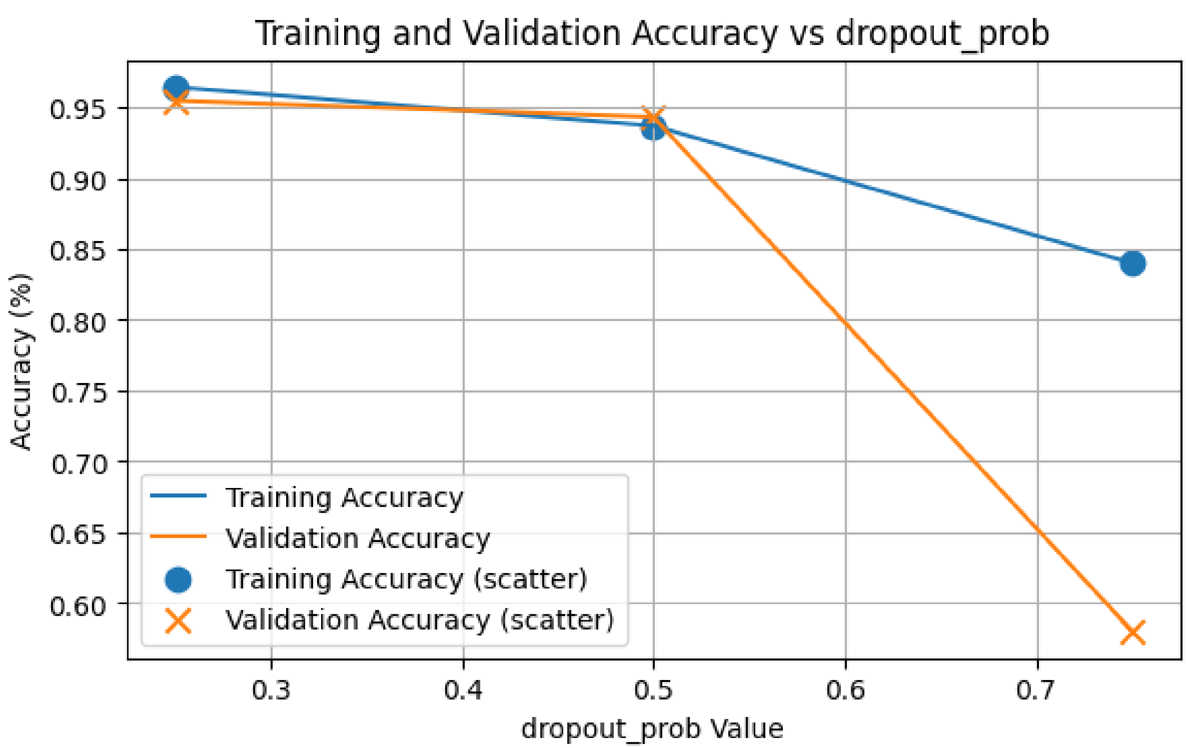


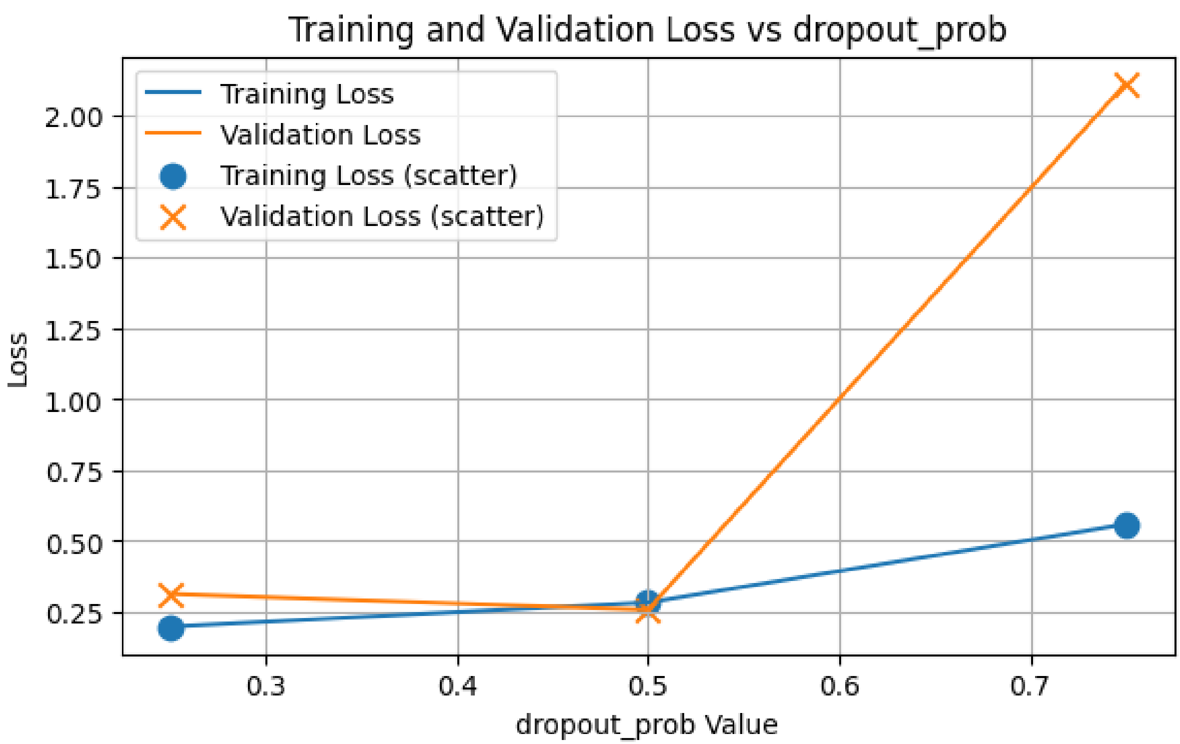

```
----------------------------------------- Accuracy and Loss for
learning_rate -----------------------------------------
```



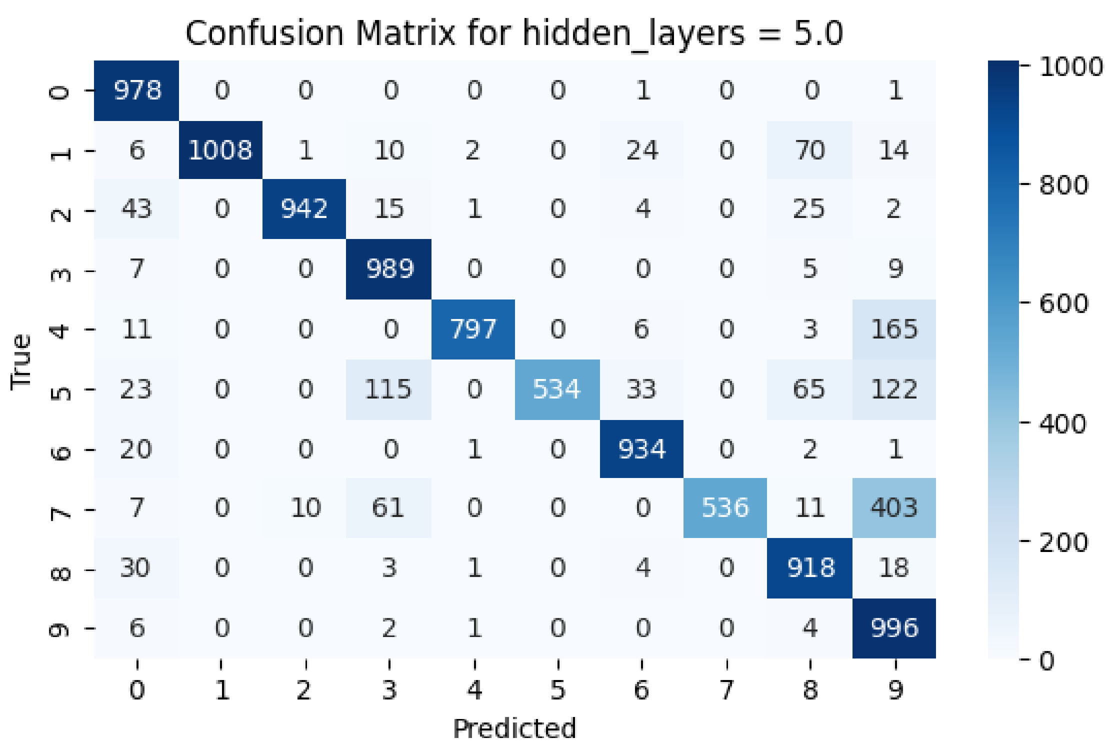


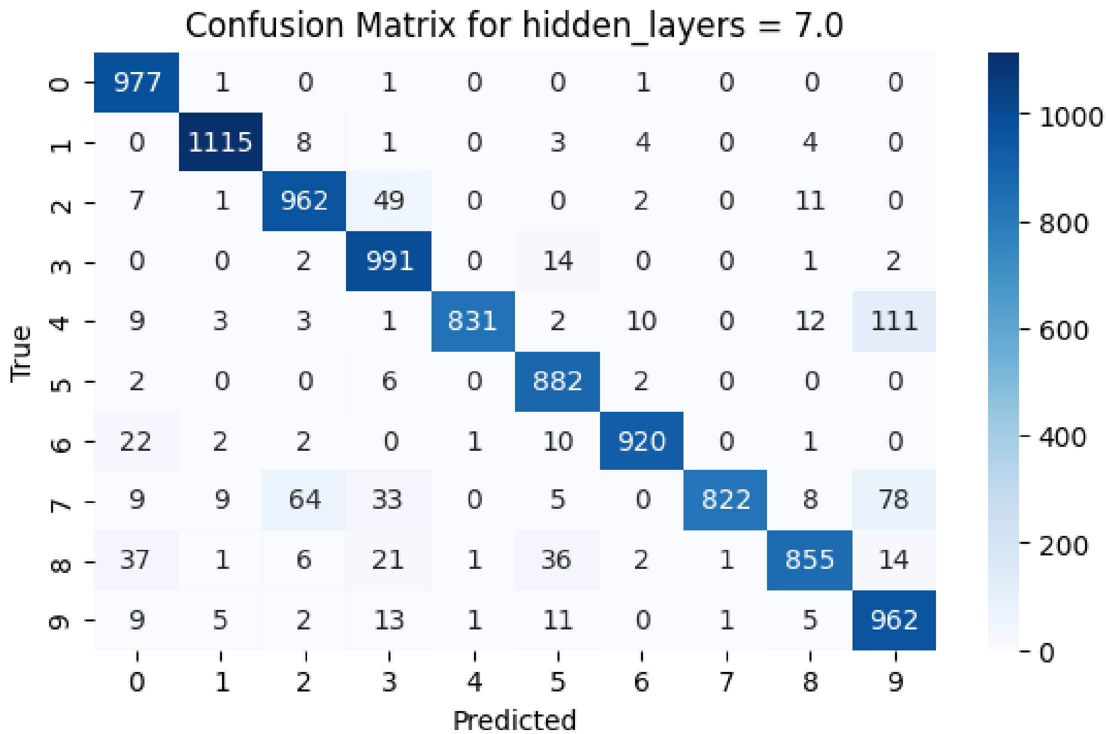

```
---------------------------------------------- Accuracy and Loss for
dropout_prob ---------------------------------------------
```

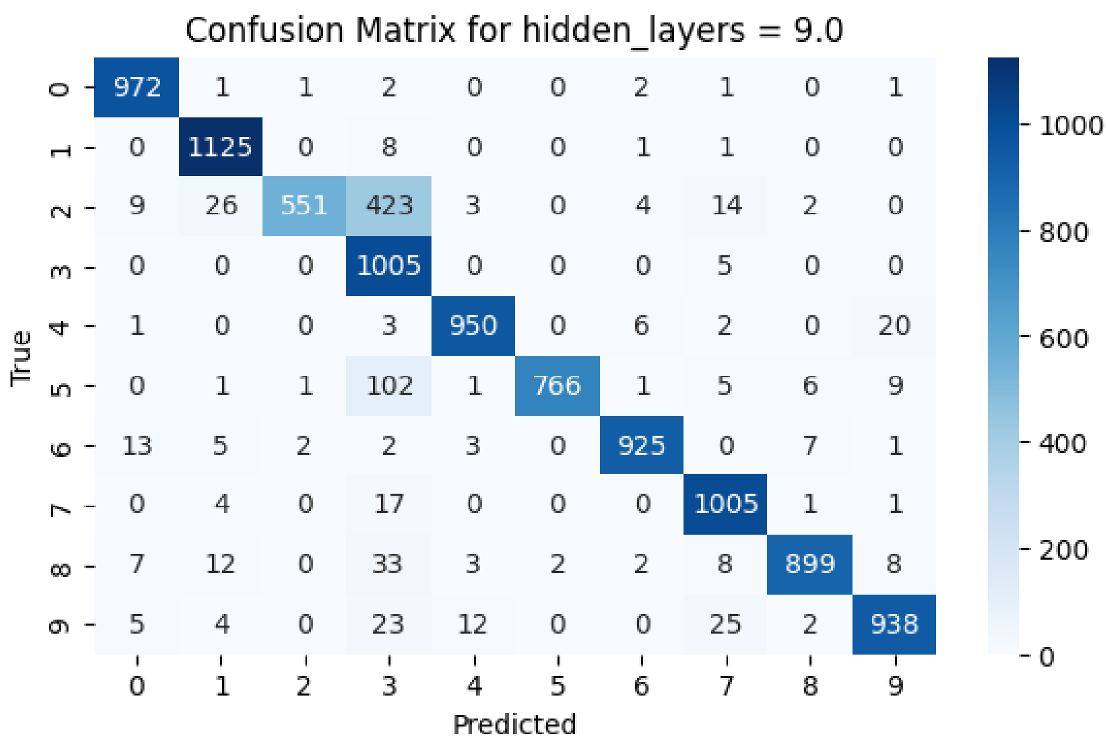


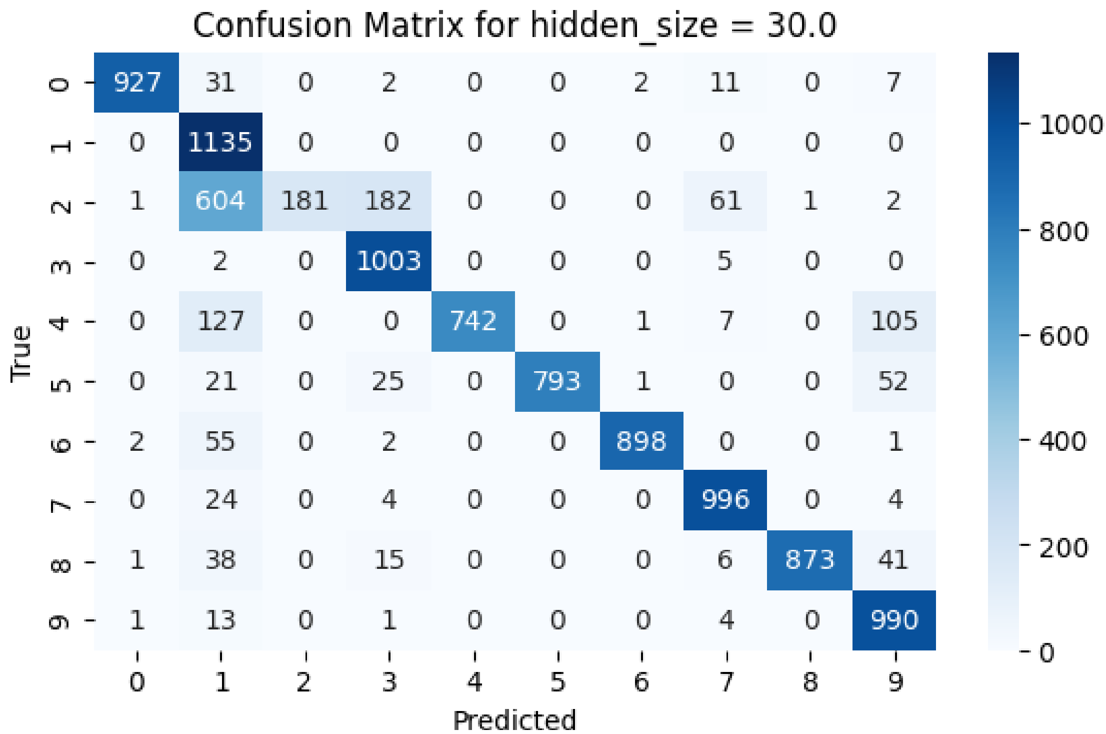


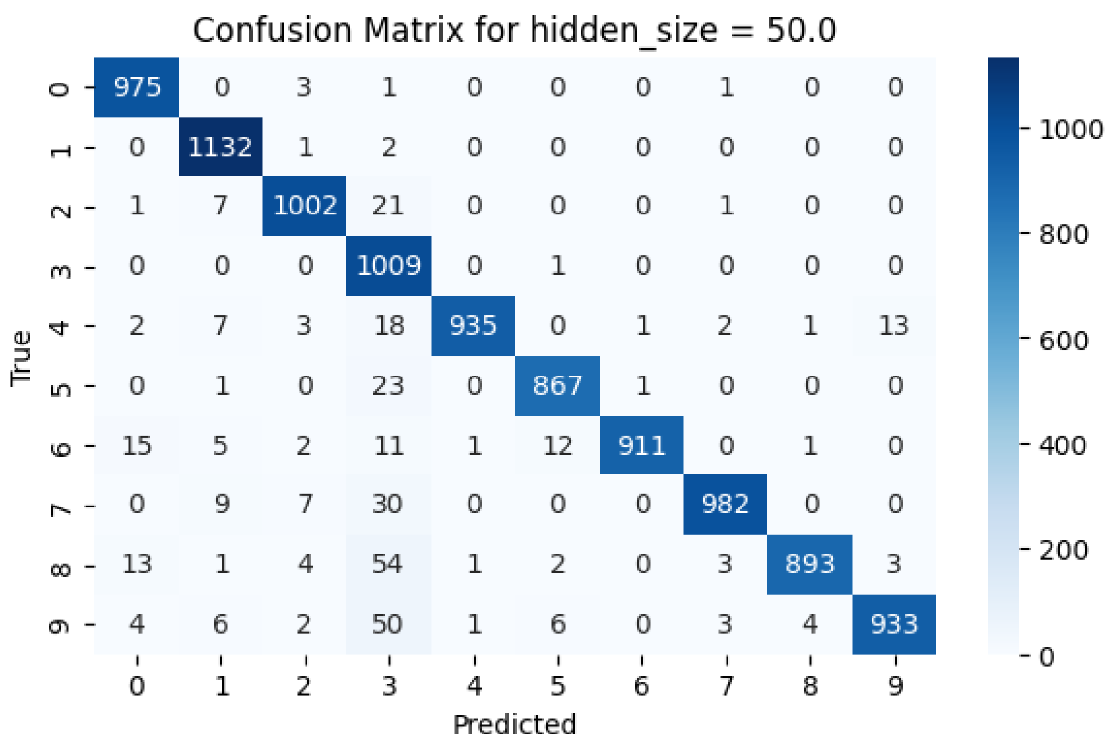

```
--------------------------------------------- Confusion Matrix for
dropout_prob --------------------------------------------
```

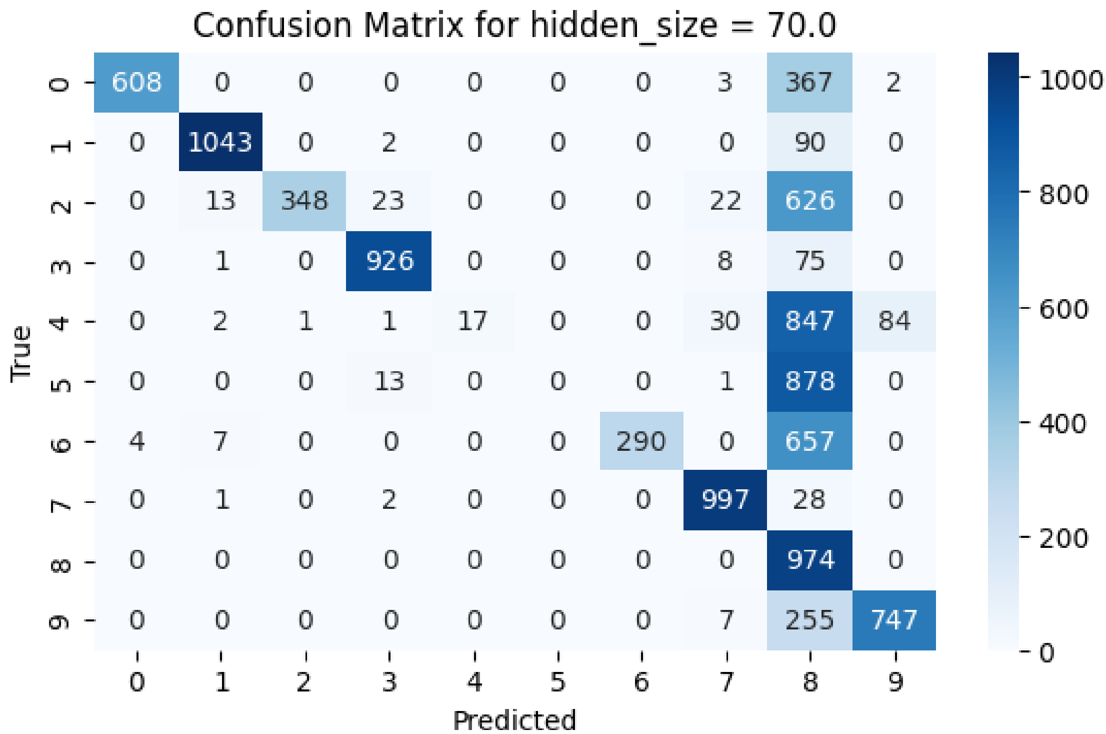



Confusion Matrix for hidden_layers = 7.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
977 1 0 1 0 0 1 0 0 0
0 1115 8 1 0 3 4 0 4 0
7 1 962 49 0 0 2 0 11 0
0 0 2 991 0 14 0 0 1 2
9 3 3 1 831 2 10 0 12 111
2 0 0 6 0 882 2 0 0 0
22 2 2 0 1 10 920 0 1 0
9 9 64 33 0 5 0 822 8 78
37 1 6 21 1 36 2 1 855 14
9 5 2 13 1 11 0 1 5 962
0
200
400
600
800
1000

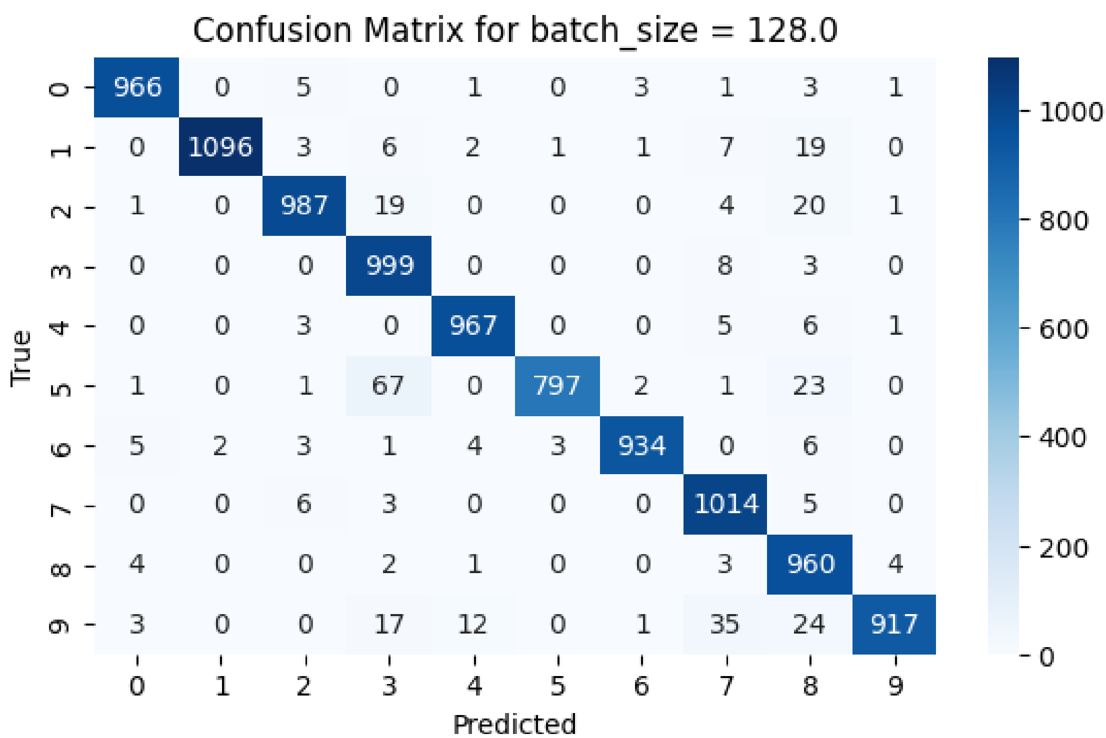

Confusion Matrix for hidden_layers = 9.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
972 1 1 2 0 0 2 1 0 1
0 1125 0 8 0 0 1 1 0 0
9 26 551 423 3 0 4 14 2 0
0 0 0 1005 0 0 0 5 0 0
1 0 0 3 950 0 6 2 0 20
0 1 1 102 1 766 1 5 6 9
13 5 2 2 3 0 925 0 7 1
0 4 0 17 0 0 0 1005 1 1
7 12 0 33 3 2 2 8 899 8
5 4 0 23 12 0 0 25 2 938
0
200
400
600
800
1000


Confusion Matrix for hidden_size = 30.0
927 31 0 2 0 0 2 11 0 7
0 1135 0 0 0 0 0 0 0 0
1 604 181 182 0 0 0 61 1 2
0 2 0 1003 0 0 0 5 0 0
0 127 0 0 742 0 1 7 0 105
0 21 0 25 0 793 1 0 0 52
2 55 0 2 0 0 898 0 0 1
0 24 0 4 0 0 0 996 0 4
1 38 0 15 0 0 0 6 873 41
1 13 0 1 0 0 0 4 0 990
True
Predicted
0 1 2 3 4 5 6 7 8 9
0 200 400 600 800 1000

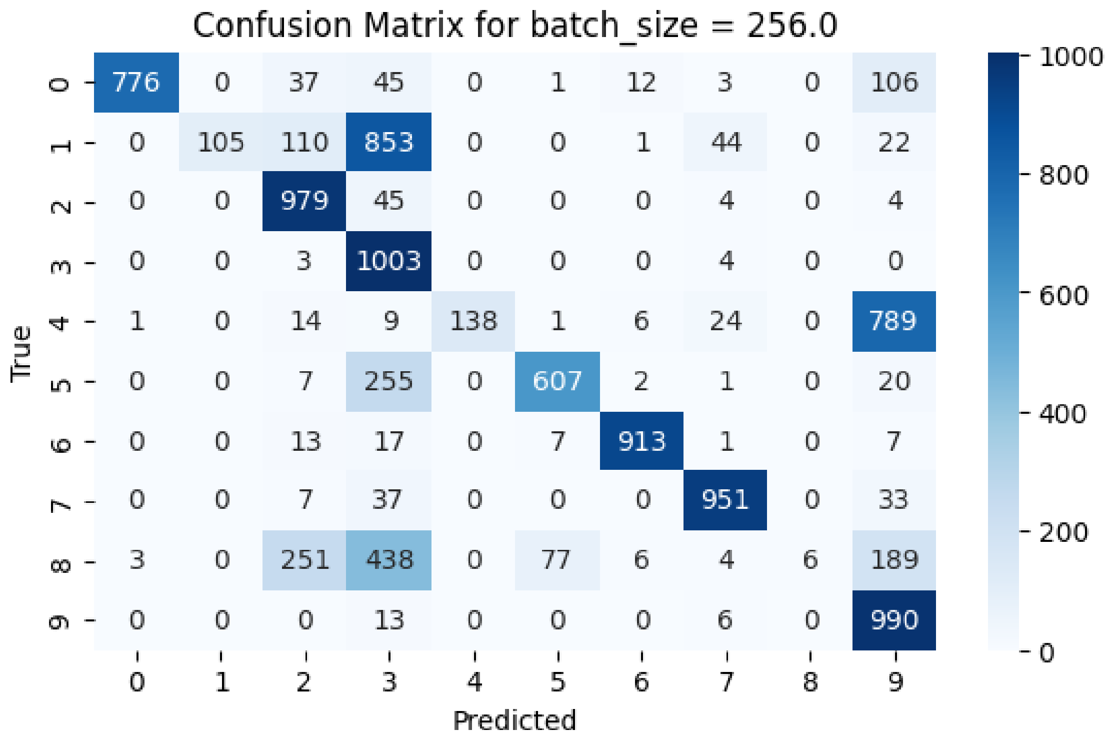

Confusion Matrix for hidden_size = 50.0
975 0 3 1 0 0 0 1 0 0
0 1132 1 2 0 0 0 0 0 0
1 7 1002 21 0 0 0 1 0 0
0 0 0 1009 0 1 0 0 0 0
2 7 3 18 935 0 1 2 1 13
0 1 0 23 0 867 1 0 0 0
15 5 2 11 1 12 911 0 1 0
0 9 7 30 0 0 0 982 0 0
13 1 4 54 1 2 0 3 893 3
4 6 2 50 1 6 0 3 4 933
True
Predicted
0 1 2 3 4 5 6 7 8 9
0 200 400 600 800 1000

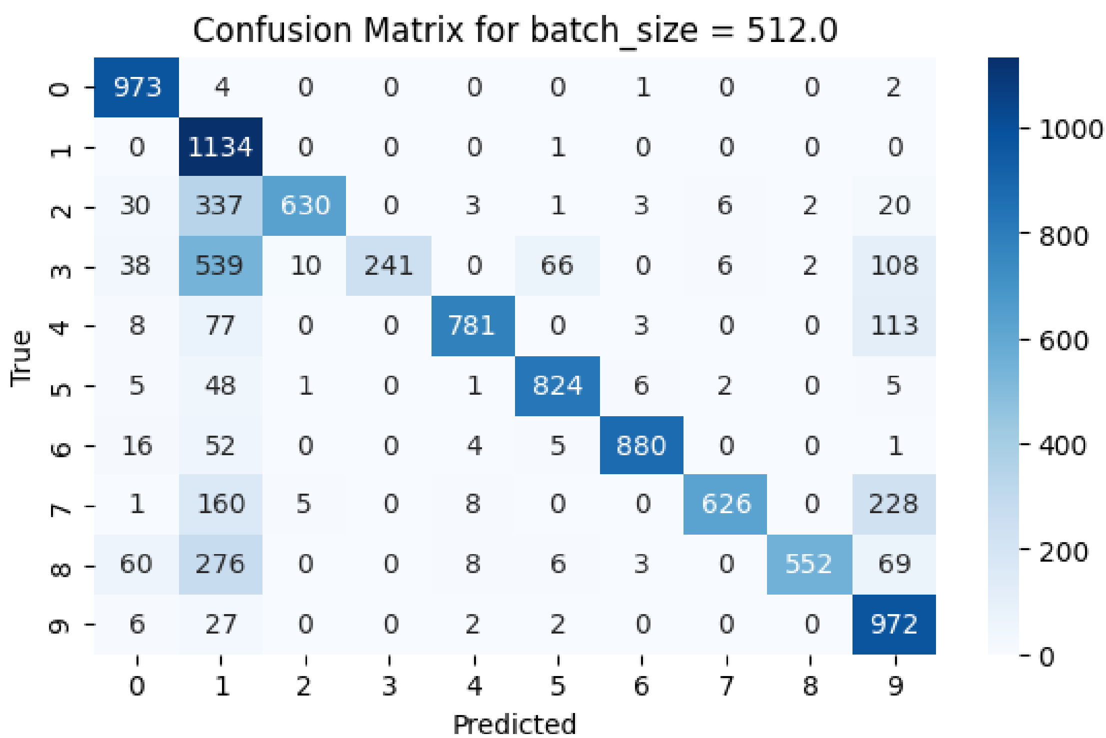


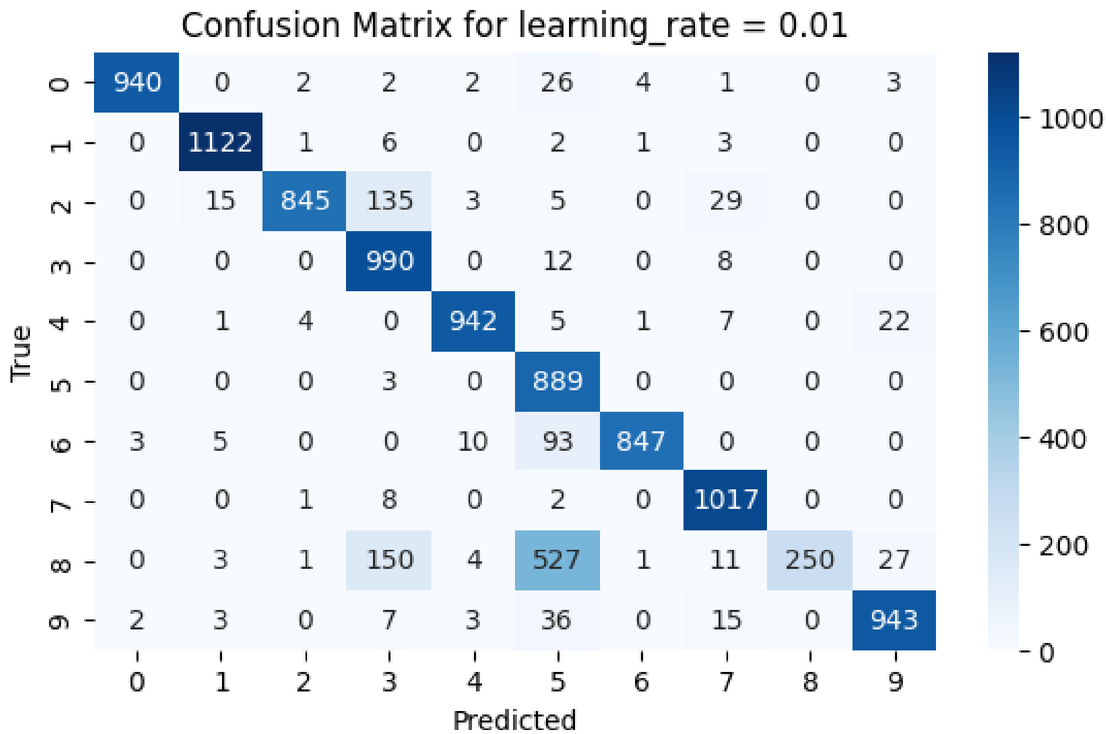
Confusion Matrix for hidden_size = 70.0
True
Predicted

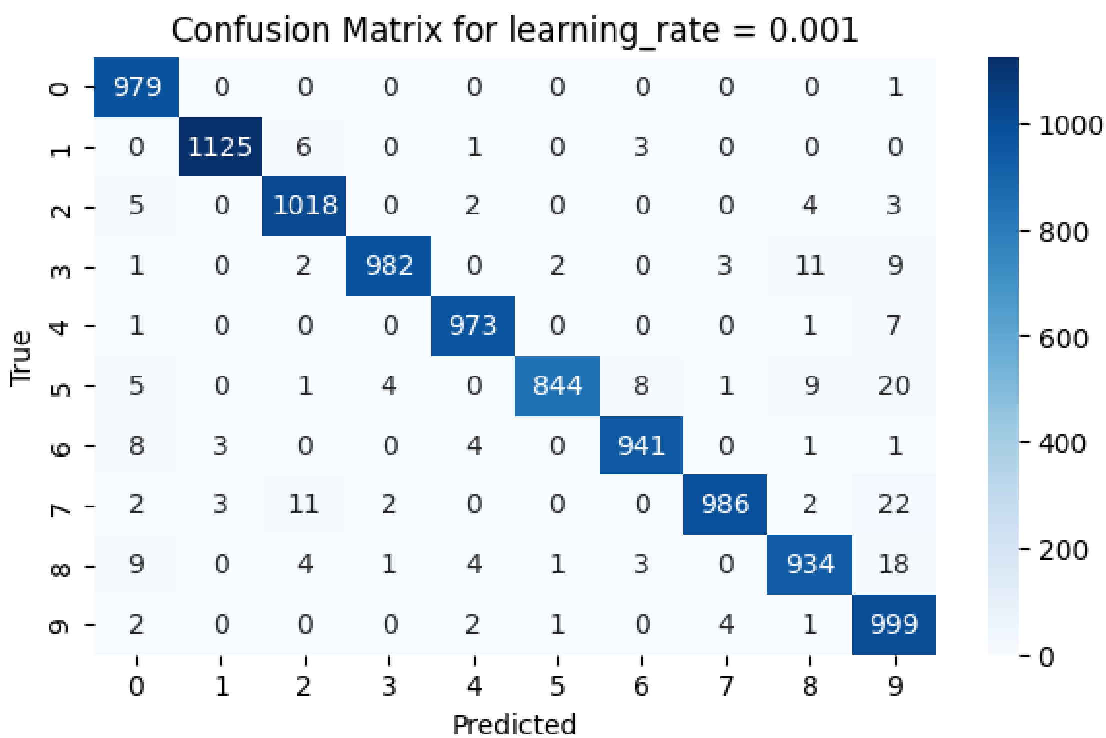


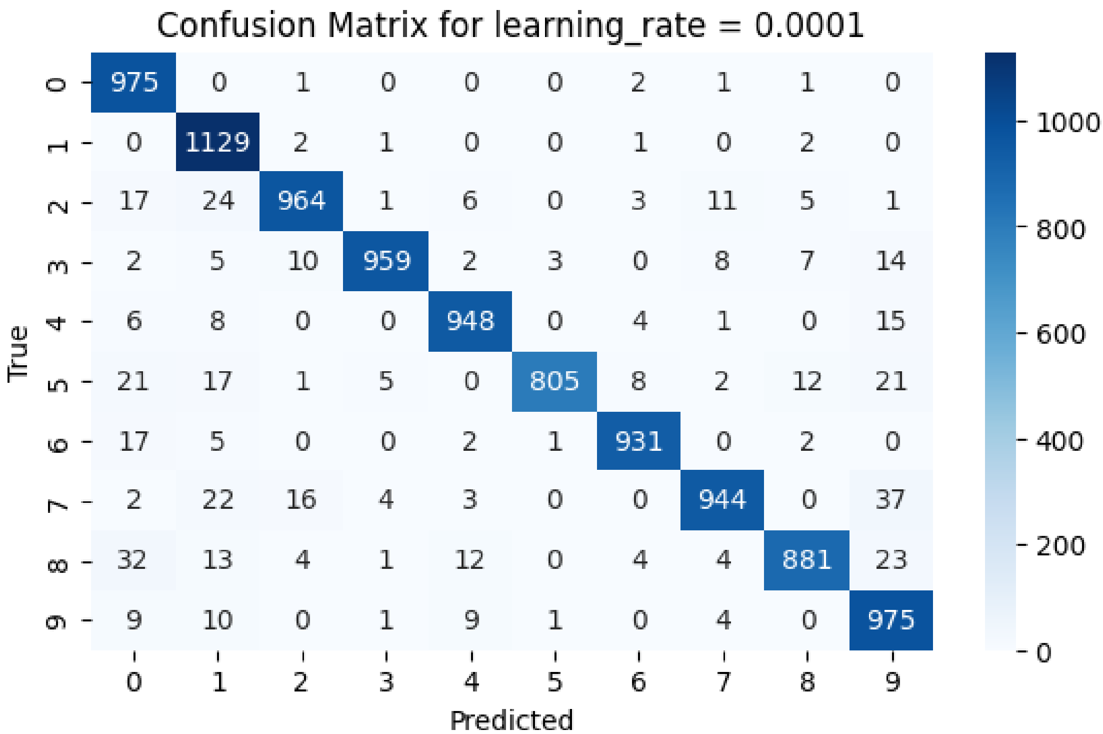
Confusion Matrix for batch_size = 128.0
True
Predicted

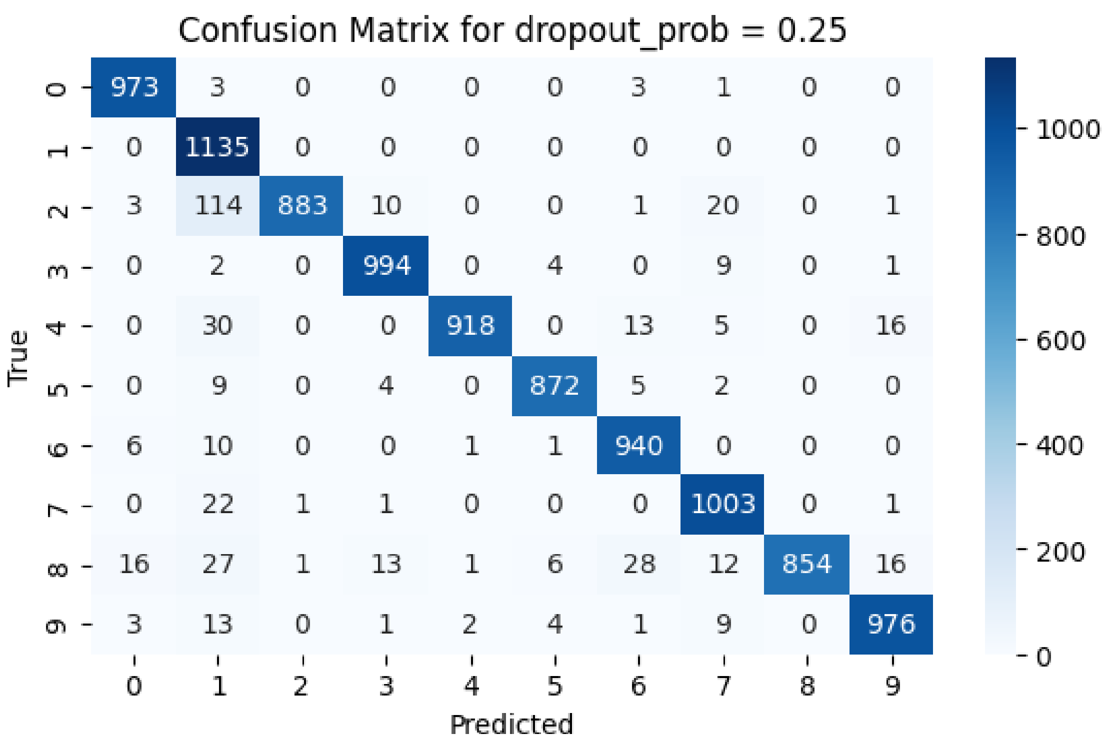

Confusion Matrix for batch_size = 256.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
776 0 37 45 0 1 12 3 0 106
0 105 110 853 0 0 1 44 0 22
0 0 979 45 0 0 0 4 0 4
0 0 3 1003 0 0 0 4 0 0
1 0 14 9 138 1 6 24 0 789
0 0 7 255 0 607 2 1 0 20
0 0 13 17 0 7 913 1 0 7
0 0 7 37 0 0 0 951 0 33
3 0 251 438 0 77 6 4 6 189
0 0 0 13 0 0 0 6 0 990
0 200 400 600 800 1000

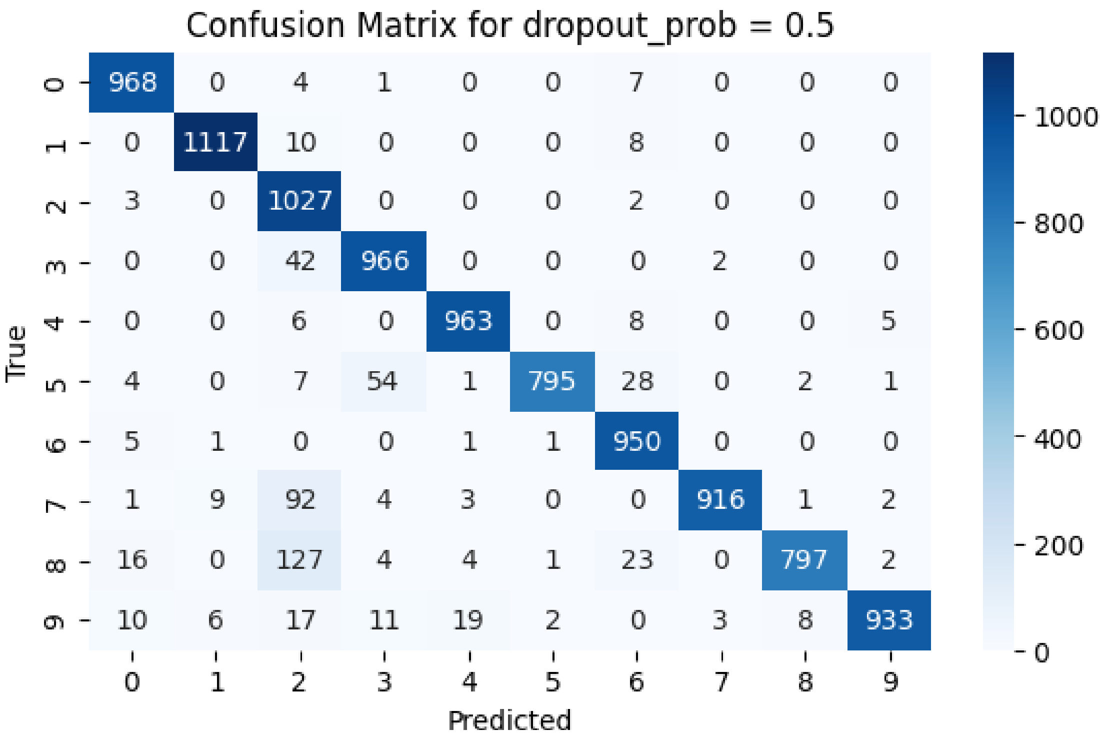

Confusion Matrix for batch_size = 512.0
True
Predicted
0 1 2 3 4 5 6 7 8 9
973 4 0 0 0 0 1 0 0 2
0 1134 0 0 0 1 0 0 0 0
30 337 630 0 3 1 3 6 2 20
38 539 10 241 0 66 0 6 2 108
8 77 0 0 781 0 3 0 0 113
5 48 1 0 1 824 6 2 0 5
16 52 0 0 4 5 880 0 0 1
1 160 5 0 8 0 0 626 0 228
60 276 0 0 8 6 3 0 552 69
6 27 0 0 2 2 0 0 0 972
0 200 400 600 800 1000

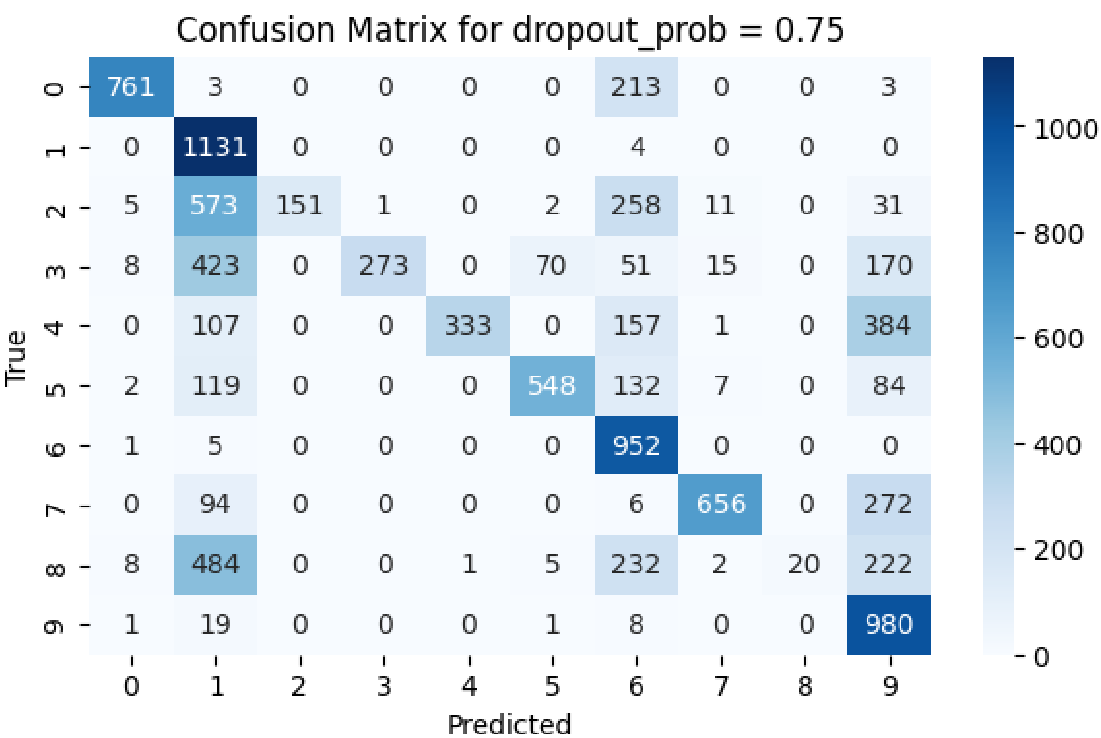

Confusion Matrix for learning_rate = 0.01
True
Predicted
0 1 2 3 4 5 6 7 8 9
940 0 2 2 2 26 4 1 0 3
0 1122 1 6 0 2 1 3 0 0
0 15 845 135 3 5 0 29 0 0
0 0 0 990 0 12 0 8 0 0
0 1 4 0 942 5 1 7 0 22
0 0 0 3 0 889 0 0 0 0
3 5 0 0 10 93 847 0 0 0
0 0 1 8 0 2 0 1017 0 0
0 3 1 150 4 527 1 11 250 27
2 3 0 7 3 36 0 15 0 943
0 200 400 600 800 1000


Confusion Matrix for learning_rate = 0.001
True
Predicted
0 1 2 3 4 5 6 7 8 9
979 0 0 0 0 0 0 0 0 1
0 1125 6 0 1 0 3 0 0 0
5 0 1018 0 2 0 0 0 4 3
1 0 2 982 0 2 0 3 11 9
1 0 0 0 973 0 0 0 1 7
5 0 1 4 0 844 8 1 9 20
8 3 0 0 4 0 941 0 1 1
2 3 11 2 0 0 0 986 2 22
9 0 4 1 4 1 3 0 934 18
2 0 0 0 2 1 0 4 1 999
0 200 400 600 800 1000


Confusion Matrix for learning_rate = 0.0001
975 0 1 0 0 0 2 1 1 0
0 1129 2 1 0 0 1 0 2 0
17 24 964 1 6 0 3 11 5 1
2 5 10 959 2 3 0 8 7 14
6 8 0 0 948 0 4 1 0 15
21 17 1 5 0 805 8 2 12 21
17 5 0 0 2 1 931 0 2 0
2 22 16 4 3 0 0 944 0 37
32 13 4 1 12 0 4 4 881 23
9 10 0 1 9 1 0 4 0 975
True
Predicted
0 1 2 3 4 5 6 7 8 9
1000
800
600
400
200
0


Confusion Matrix for dropout_prob = 0.25
973 3 0 0 0 0 3 1 0 0
0 1135 0 0 0 0 0 0 0 0
3 114 883 10 0 0 1 20 0 1
0 2 0 994 0 4 0 9 0 1
0 30 0 0 918 0 13 5 0 16
0 9 0 4 0 872 5 2 0 0
6 10 0 0 1 1 940 0 0 0
0 22 1 1 0 0 0 1003 0 1
16 27 1 13 1 6 28 12 854 16
3 13 0 1 2 4 1 9 0 976
True
Predicted
0 1 2 3 4 5 6 7 8 9
1000
800
600
400
200
0


Confusion Matrix for dropout_prob = 0.5
True
Predicted
0 1 2 3 4 5 6 7 8 9
968 0 4 1 0 0 7 0 0 0
0 1117 10 0 0 0 8 0 0 0
3 0 1027 0 0 0 2 0 0 0
0 0 42 966 0 0 0 2 0 0
0 0 6 0 963 0 8 0 0 5
4 0 7 54 1 795 28 0 2 1
5 1 0 0 1 1 950 0 0 0
1 9 92 4 3 0 0 916 1 2
16 0 127 4 4 1 23 0 797 2
10 6 17 11 19 2 0 3 8 933
0
200
400
600
800
1000


Confusion Matrix for dropout_prob = 0.75
True
Predicted
0 1 2 3 4 5 6 7 8 9
761 3 0 0 0 0 213 0 0 3
0 1131 0 0 0 0 4 0 0 0
5 573 151 1 0 2 258 11 0 31
8 423 0 273 0 70 51 15 0 170
0 107 0 0 333 0 157 1 0 384
2 119 0 0 0 548 132 7 0 84
1 5 0 0 0 0 952 0 0 0
0 94 0 0 0 0 6 656 0 272
8 484 0 0 1 5 232 2 20 222
1 19 0 0 0 1 8 0 0 980
0
200
400
600
800
1000