1.a

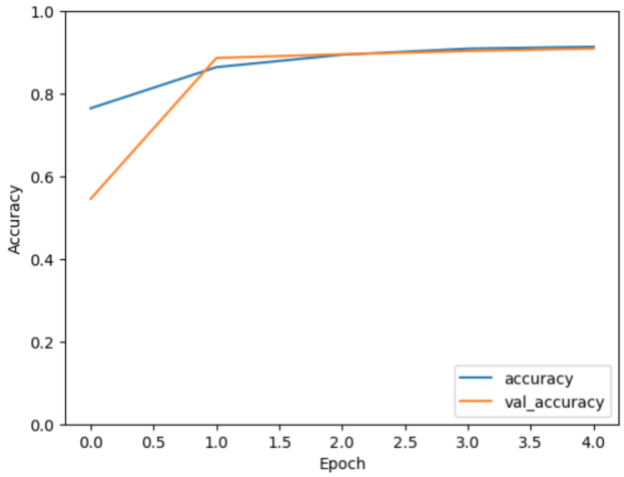
Evaluation results

```
# Evaluate the model on the test data
test_loss, test_acc = model.evaluate(test_images, test_labels)
print('Test accuracy:', test_acc)
```

```
313/313 [==============================] - 25s 79ms/step - loss: 0.3067 - accuracy: 0.9018
Test accuracy: 0.9017999768257141
```

The reported accuracy on Test is: 0.9017999768257141

Learning Curve



Model Summary

Layer (type)	Output Shape	Param #
conv2d_192 (Conv2D)	(None, 28, 28, 32)	320
batch_normalization_184 (BatchNormalization)	(None, 28, 28, 32)	128
max_pooling2d_48 (MaxPooling2D)	(None, 14, 14, 32)	0
conv2d_193 (Conv2D)	(None, 14, 14, 64)	18496
batch_normalization_185 (BatchNormalization)	(None, 14, 14, 64)	256
max_pooling2d_49 (MaxPooling2D)	(None, 7, 7, 64)	0
conv2d_194 (Conv2D)	(None, 7, 7, 128)	73856
batch_normalization_186 (BatchNormalization)	(None, 7, 7, 128)	512
conv2d_195 (Conv2D)	(None, 7, 7, 256)	295168
batch_normalization_187 (BatchNormalization)	(None, 7, 7, 256)	1024
conv2d_196 (Conv2D)	(None, 7, 7, 512)	1180160
batch_normalization_188 (BatchNormalization)	(None, 7, 7, 512)	2048
flatten_20 (Flatten)	(None, 25088)	0
dense_70 (Dense)	(None, 256)	6422784
dropout_40 (Dropout)	(None, 256)	0

1.b

Evaluation Results

```
Epoch 1/2
375/375 [==============================] - 541s 1s/step - loss: 0.7716 - accuracy: 0.7763 - val_loss: 2.4032 - val_ac
curacy: 0.7273
Epoch 2/2
375/375 [==============================] - 544s 1s/step - loss: 0.4358 - accuracy: 0.8586 - val_loss: 0.4152 - val_ac
curacy: 0.8808
313/313 - 24s - loss: 0.4192 - accuracy: 0.8776 - 24s/epoch - 77ms/step
Epoch 1/2
375/375 [==============================] - 2246s 6s/step - loss: 0.8204 - accuracy: 0.7650 - val_loss: 1.6018 - val_a
ccuracy: 0.5418
Epoch 2/2
375/375 [==============================] - 546s 1s/step - loss: 0.3934 - accuracy: 0.8686 - val_loss: 0.3915 - val_ac
curacy: 0.8807
313/313 - 25s - loss: 0.4187 - accuracy: 0.8776 - 25s/epoch - 80ms/step
Epoch 1/2
375/375 [==============================] - 532s 1s/step - loss: 0.8341 - accuracy: 0.7590 - val_loss: 56.4212 - val_a
ccuracy: 0.2085
Epoch 2/2
375/375 [==============================] - 538s 1s/step - loss: 0.4169 - accuracy: 0.8583 - val_loss: 0.3105 - val_ac
curacy: 0.8914
313/313 - 27s - loss: 0.3358 - accuracy: 0.8825 - 27s/epoch - 85ms/step
Epoch 1/2
375/375 [==============================] - 657s 2s/step - loss: 0.8061 - accuracy: 0.7702 - val_loss: 27.3161 - val_a
ccuracy: 0.2720
Epoch 2/2
375/375 [==============================] - 1639s 4s/step - loss: 0.3612 - accuracy: 0.8771 - val_loss: 0.3319 - val_a
ccuracy: 0.8896
313/313 - 26s - loss: 0.3488 - accuracy: 0.8831 - 26s/epoch - 83ms/step
Epoch 1/2
375/375 [==============================] - 547s 1s/step - loss: 0.8811 - accuracy: 0.7446 - val_loss: 13.9537 - val_a
ccuracy: 0.5340
Epoch 2/2
375/375 [==============================] - 606s 2s/step - loss: 0.3876 - accuracy: 0.8678 - val_loss: 0.3160 - val_ac
curacy: 0.8913
313/313 - 26s - loss: 0.3304 - accuracy: 0.8855 - 26s/epoch - 82ms/step
Average accuracy: 0.8812600016593933
Standard deviation: 0.0031525162292539545
```

Model Summary

Layer (type)	Output Shape	Param #
conv2d_192 (Conv2D)	(None, 28, 28, 32)	320
batch_normalization_184 (BatchNormalization)	(None, 28, 28, 32)	128
max_pooling2d_48 (MaxPooling2D)	(None, 14, 14, 32)	0
conv2d_193 (Conv2D)	(None, 14, 14, 64)	18496
batch_normalization_185 (BatchNormalization)	(None, 14, 14, 64)	256
max_pooling2d_49 (MaxPooling2D)	(None, 7, 7, 64)	0
conv2d_194 (Conv2D)	(None, 7, 7, 128)	73856
batch_normalization_186 (BatchNormalization)	(None, 7, 7, 128)	512
conv2d_195 (Conv2D)	(None, 7, 7, 256)	295168
batch_normalization_187 (BatchNormalization)	(None, 7, 7, 256)	1024
conv2d_196 (Conv2D)	(None, 7, 7, 512)	1180160
batch_normalization_188 (BatchNormalization)	(None, 7, 7, 512)	2048
flatten_20 (Flatten)	(None, 25088)	0
dense_70 (Dense)	(None, 256)	6422784
dropout_40 (Dropout)	(None, 256)	0

1.c

Evaluation Results

```
Hyperparameter Combinations and Test Accuracies:
('relu', 'Adam', 16, 0.001) 0.7188000082969666
('relu', 'Adam', 16, 0.0001) 0.47940000891685486
('relu', 'Adam', 16, 1e-05) 0.7520999908447266
('relu', 'Adam', 32, 0.001) 0.7659000158309937

Optimal Hyperparameters:
('relu', 'Adam', 32, 0.001) with Test Accuracy: 0.7659000158309937
```

Model Summary

Layer (type)	Output Shape	Param #
conv2d_217 (Conv2D)	(None, 28, 28, 32)	320
batch_normalization_209 (BatchNormalization)	(None, 28, 28, 32)	128
max_pooling2d_58 (MaxPooling2D)	(None, 14, 14, 32)	0
conv2d_218 (Conv2D)	(None, 14, 14, 64)	18496
batch_normalization_210 (BatchNormalization)	(None, 14, 14, 64)	256
max_pooling2d_59 (MaxPooling2D)	(None, 7, 7, 64)	0
conv2d_219 (Conv2D)	(None, 7, 7, 128)	73856
batch_normalization_211 (BatchNormalization)	(None, 7, 7, 128)	512
conv2d_220 (Conv2D)	(None, 7, 7, 256)	295168
batch_normalization_212 (BatchNormalization)	(None, 7, 7, 256)	1024
conv2d_221 (Conv2D)	(None, 7, 7, 512)	1180160
batch_normalization_213 (BatchNormalization)	(None, 7, 7, 512)	2048
flatten_25 (Flatten)	(None, 25088)	0
dense_85 (Dense)	(None, 256)	6422784
dropout_50 (Dropout)	(None, 256)	0
dense_86 (Dense)	(None, 128)	32896
dropout_51 (Dropout)	(None, 128)	0
dense_87 (Dense)	(None, 10)	1290

```
Total params: 8028938 (30.63 MB)
Trainable params: 8026954 (30.62 MB)
Non-trainable params: 1984 (7.75 KB)
```

1.d.

Evaluation Results

```
Epoch 1/2
1875/1875 [==============================] - 328s 173ms/step - loss: 1.1491 - accuracy: 0.6017
Epoch 2/2
1875/1875 [==============================] - 290s 155ms/step - loss: 0.7484 - accuracy: 0.7026
Test Accuracy: 0.7563999891281128
```

Evaluation results: 0.7563999891281128

Model Summary

```
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_4 (Conv2D)           (None, 28, 28, 16)        160

 batch_normalization_4 (Bat  (None, 28, 28, 16)        64
 chNormalization)

 max_pooling2d_2 (MaxPoolin  (None, 14, 14, 16)        0
 g2D)

 conv2d_5 (Conv2D)           (None, 14, 14, 32)        4640

 batch_normalization_5 (Bat  (None, 14, 14, 32)        128
 chNormalization)

 max_pooling2d_3 (MaxPoolin  (None, 7, 7, 32)          0
 g2D)

 conv2d_6 (Conv2D)           (None, 7, 7, 64)          18496

 batch_normalization_6 (Bat  (None, 7, 7, 64)          256
 chNormalization)

 conv2d_7 (Conv2D)           (None, 7, 7, 128)         73856

 batch_normalization_7 (Bat  (None, 7, 7, 128)         512
 chNormalization)

 conv2d_8 (Conv2D)           (None, 7, 7, 256)         295168

 batch_normalization_8 (Bat  (None, 7, 7, 256)         1024
 chNormalization)

 flatten_1 (Flatten)         (None, 12544)             0

 dense_3 (Dense)             (None, 256)               3211520

 dropout_2 (Dropout)         (None, 256)               0
```

1.e.

VGG Model Summary

Layer (type)	Output Shape	Param #
input_1 (InputLayer)	[(None, 224, 224, 3)]	0
block1_conv1 (Conv2D)	(None, 224, 224, 64)	1792
block1_conv2 (Conv2D)	(None, 224, 224, 64)	36928
block1_pool (MaxPooling2D)	(None, 112, 112, 64)	0
block2_conv1 (Conv2D)	(None, 112, 112, 128)	73856
block2_conv2 (Conv2D)	(None, 112, 112, 128)	147584
block2_pool (MaxPooling2D)	(None, 56, 56, 128)	0
block3_conv1 (Conv2D)	(None, 56, 56, 256)	295168
block3_conv2 (Conv2D)	(None, 56, 56, 256)	590080
block3_conv3 (Conv2D)	(None, 56, 56, 256)	590080
block3_conv4 (Conv2D)	(None, 56, 56, 256)	590080
block3_pool (MaxPooling2D)	(None, 28, 28, 256)	0
block4_conv1 (Conv2D)	(None, 28, 28, 512)	1180160
global_average_pooling2d_3 (GlobalAveragePooling2D)	(None, 512)	0
dense_10 (Dense)	(None, 256)	131328
dense_11 (Dense)	(None, 10)	2570

Total params: 3639626 (13.88 MB)
Trainable params: 133898 (523.04 KB)
Non-trainable params: 3505728 (13.37 MB)

Problem 2

Evaluation results

Evaluate the model

```
loss, accuracy = loaded_model.evaluate(x_test, y_test)

print(f"Test loss: {loss}")
print(f"Test accuracy: {accuracy}")
```

```
313/313 [==============================] - 232s 738ms/step - loss: 2.3410 - accuracy: 0.0385
Test loss: 2.341022491455078
Test accuracy: 0.03849999979138374
```

Model Summary

Layer (type)	Output Shape	Param #	Connected to
input_6 (InputLayer)	[(None, 28, 28, 1)]	0	[]
conv2d_141 (Conv2D)	(None, 28, 28, 32)	320	['input_6[0][0]']
batch_normalization_135 (BatchNormalization)	(None, 28, 28, 32)	128	['conv2d_141[0][0]']
re_lu_65 (ReLU)	(None, 28, 28, 32)	0	['batch_normalization_135[0][0]']
conv2d_142 (Conv2D)	(None, 28, 28, 32)	9248	['re_lu_65[0][0]']
batch_normalization_136 (BatchNormalization)	(None, 28, 28, 32)	128	['conv2d_142[0][0]']
re_lu_66 (ReLU)	(None, 28, 28, 32)	0	['batch_normalization_136[0][0]']
conv2d_143 (Conv2D)	(None, 28, 28, 32)	9248	['re_lu_66[0][0]']
batch_normalization_137 (BatchNormalization)	(None, 28, 28, 32)	128	['conv2d_143[0][0]']
add_61 (Add)	(None, 28, 28, 32)	0	['batch_normalization_137[0][0]', 're_lu_65[0][0]']
conv2d_144 (Conv2D)	(None, 28, 28, 32)	9248	['add_61[0][0]']
batch_normalization_138 (BatchNormalization)	(None, 28, 28, 32)	128	['conv2d_144[0][0]']
re_lu_68 (ReLU)	(None, 28, 28, 32)	0	['batch_normalization_138[0][0]']
conv2d_145 (Conv2D)	(None, 28, 28, 32)	9248	['re_lu_68[0][0]']