



Bangladesh University of Engineering and Technology

Assignment 3: Function Approximation with Neural Network
and Backpropagation

Name: Rakib Kibria

Id: 1905098

Course: CSE - 472

Lab Group: B2

Running my code

1. Create python virtual environment `python3 -m venv .venv`
2. Activate the virtual environment `source .venv/bin/activate` for linux distribution
3. Install requirements `pip install -r requirements.txt`

Model Architecture:

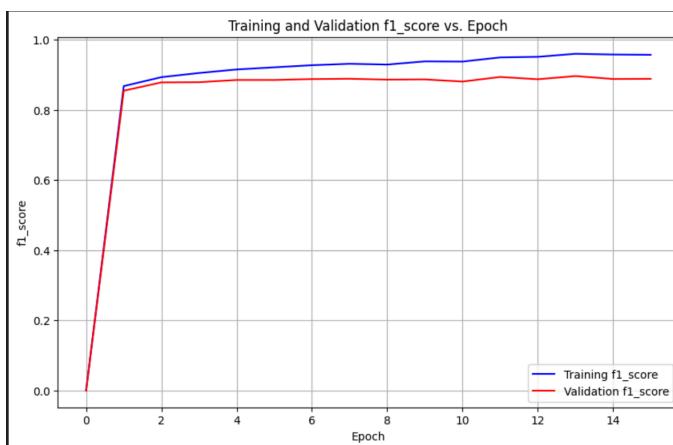
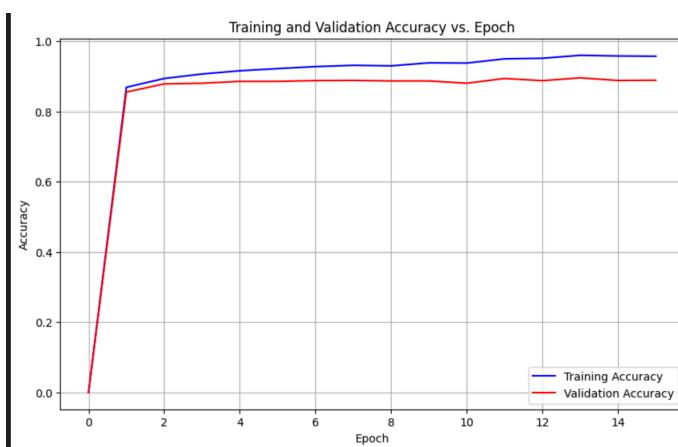
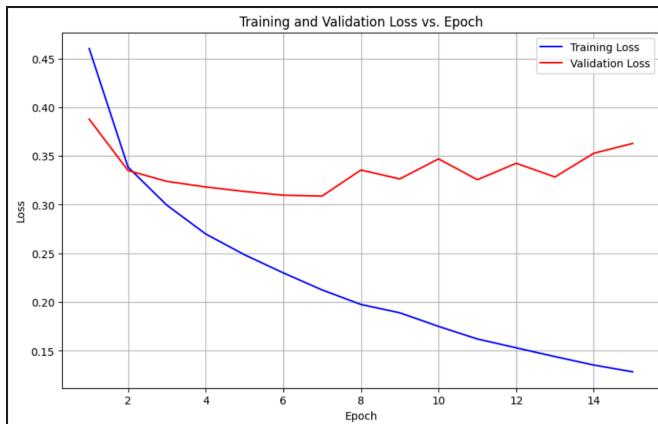
```
NeuralNetwork.add_layer(Dense(784, 256))
NeuralNetwork.add_layer(BatchNormalization(256))
NeuralNetwork.add_layer(ActivationLayer('Relu'))
NeuralNetwork.add_layer(Dense(256, 64))
NeuralNetwork.add_layer(BatchNormalization(64))
NeuralNetwork.add_layer(ActivationLayer('Relu'))
NeuralNetwork.add_layer(Dense(64, total_class))
NeuralNetwork.add_layer(ActivationLayer('Softmax'))
```

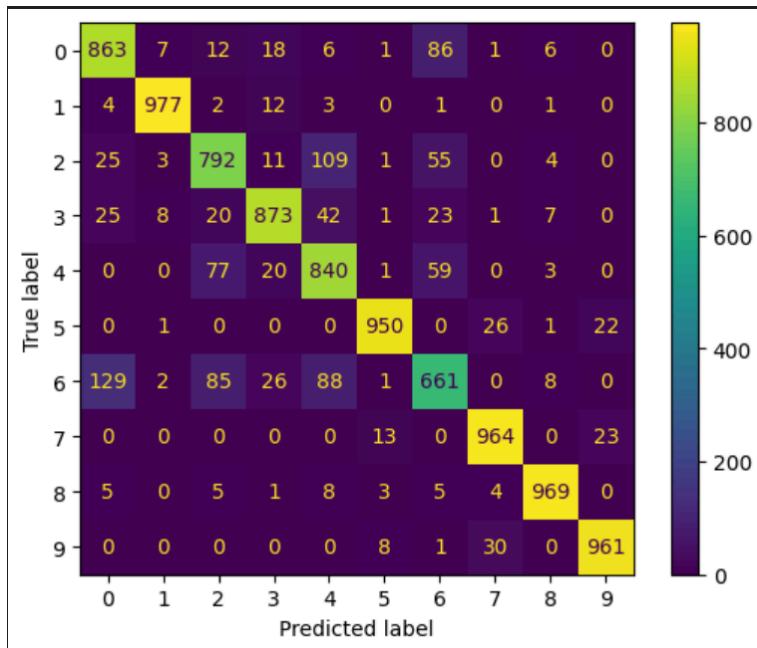
Hyperparameters: **Learning rate: alpha = 0.005**, Batch Size: 256, Epoch = 15

```
Validation Loss: 0.362816841108166
Validation Accuracy: 88.90%
Validation f1_score: 88.87%
```

```
Test loss: 0.39021195021336935
Test Accuracy: 88.5%
Test f1_score: 88.44610248079%
```

```
Epoch 1, Training Loss: 0.46015688105239066 Training Accuracy: 0.868875%
Validation Loss: 0.3877048066793875 Validation Accuracy: 85.52% Validation f1_score: 85.48%
100%|██████| 188/188 [00:02<00:00, 90.24it/s]
Epoch 2, Training Loss: 0.33852934394356965 Training Accuracy: 0.8938333333333334%
Validation Loss: 0.3350462860494663 Validation Accuracy: 87.85% Validation f1_score: 87.84%
100%|██████| 188/188 [00:02<00:00, 81.63it/s]
Epoch 3, Training Loss: 0.29944952763971994 Training Accuracy: 0.9066666666666666%
Validation Loss: 0.32391305538461956 Validation Accuracy: 88.03% Validation f1_score: 87.90%
100%|██████| 188/188 [00:01<00:00, 94.24it/s]
Epoch 4, Training Loss: 0.269938901988504 Training Accuracy: 0.915875%
Validation Loss: 0.3181731854033721 Validation Accuracy: 88.57% Validation f1_score: 88.54%
100%|██████| 188/188 [00:02<00:00, 79.33it/s]
Epoch 5, Training Loss: 0.2485784456320012 Training Accuracy: 0.9219583333333333%
Validation Loss: 0.31355441555828506 Validation Accuracy: 88.56% Validation f1_score: 88.53%
100%|██████| 188/188 [00:02<00:00, 82.24it/s]
Epoch 6, Training Loss: 0.22997208509905423 Training Accuracy: 0.9277083333333334%
Validation Loss: 0.30968627457003434 Validation Accuracy: 88.79% Validation f1_score: 88.80%
100%|██████| 188/188 [00:01<00:00, 101.65it/s]
Epoch 7, Training Loss: 0.21248445227831553 Training Accuracy: 0.931375%
Validation Loss: 0.30886500835369923 Validation Accuracy: 88.85% Validation f1_score: 88.88%
100%|██████| 188/188 [00:01<00:00, 99.86it/s]
Epoch 8, Training Loss: 0.19755693247641387 Training Accuracy: 0.9298541666666666%
Validation Loss: 0.33556049562464146 Validation Accuracy: 88.68% Validation f1_score: 88.63%
100%|██████| 188/188 [00:02<00:00, 83.73it/s]
Epoch 9, Training Loss: 0.1890131245905036 Training Accuracy: 0.9384583333333333%
Validation Loss: 0.32641673098680857 Validation Accuracy: 88.68% Validation f1_score: 88.69%
100%|██████| 188/188 [00:02<00:00, 86.59it/s]
Epoch 10, Training Loss: 0.17505375018187286 Training Accuracy: 0.9377916666666667%
Validation Loss: 0.3469797149806396 Validation Accuracy: 88.04% Validation f1_score: 88.08%
100%|██████| 188/188 [00:02<00:00, 70.57it/s]
Epoch 11, Training Loss: 0.16211857335685712 Training Accuracy: 0.94975%
Validation Loss: 0.32561682686198296 Validation Accuracy: 89.39% Validation f1_score: 89.40%
100%|██████| 188/188 [00:03<00:00, 56.68it/s]
Epoch 12, Training Loss: 0.15307235556964605 Training Accuracy: 0.9515%
Validation Loss: 0.3424555003424136 Validation Accuracy: 88.77% Validation f1_score: 88.74%
100%|██████| 188/188 [00:03<00:00, 56.53it/s]
Epoch 13, Training Loss: 0.1440066125353165 Training Accuracy: 0.959875%
Validation Loss: 0.3284250019434944 Validation Accuracy: 89.58% Validation f1_score: 89.65%
100%|██████| 188/188 [00:03<00:00, 54.83it/s]
Epoch 14, Training Loss: 0.13537096765398945 Training Accuracy: 0.958%
Validation Loss: 0.3527802882486982 Validation Accuracy: 88.83% Validation f1_score: 88.82%
100%|██████| 188/188 [00:03<00:00, 56.63it/s]
Epoch 15, Training Loss: 0.12842859466033016 Training Accuracy: 0.9572708333333333%
Validation Loss: 0.362816841108166 Validation Accuracy: 88.90% Validation f1_score: 88.87%
```

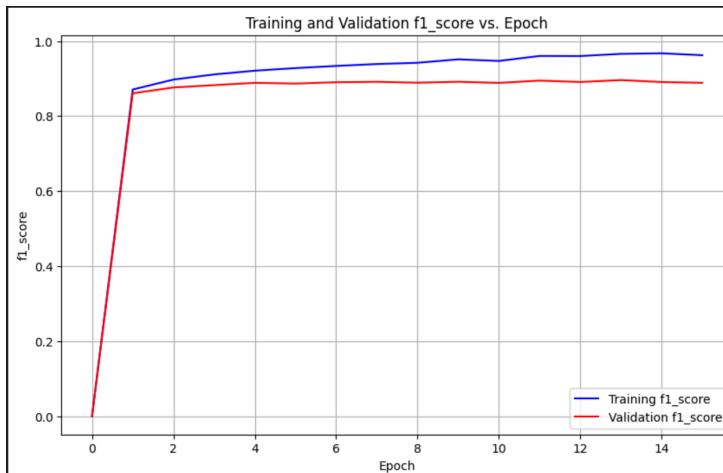
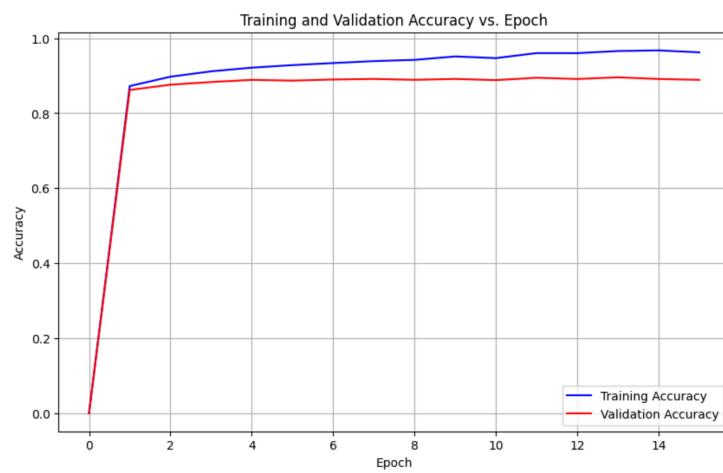
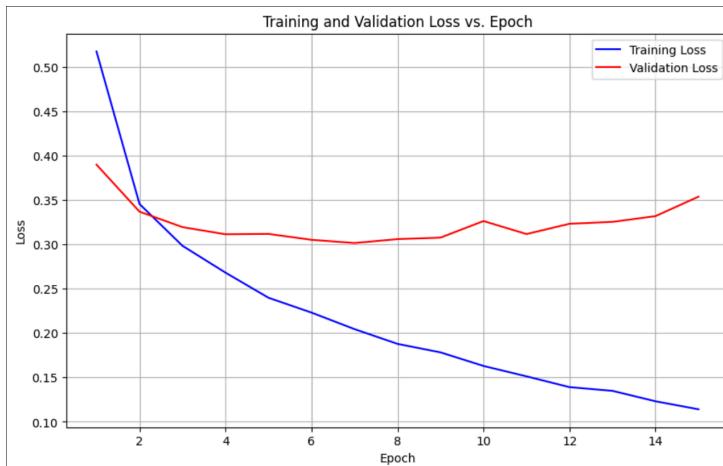


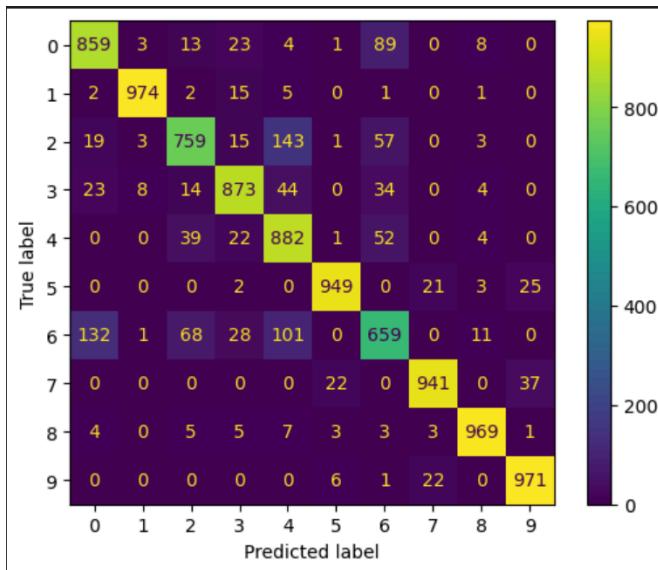


Hyperparameters: **Learning rate: alpha = 0.001**, Batch Size: 256, Epoch = 15

```
Validation Loss: 0.3536664120136583
Validation Accuracy: 88.88%
Validation f1_score: 88.86%
```

```
Test loss: 0.3772797387136933
Test Accuracy: 88.36%
Test f1_score: 88.30098791419636%
```





Hyperparameters: Learning rate: alpha = 0.0005, Batch Size: 256, Epoch = 15

Validation Loss: 0.33324445765378174

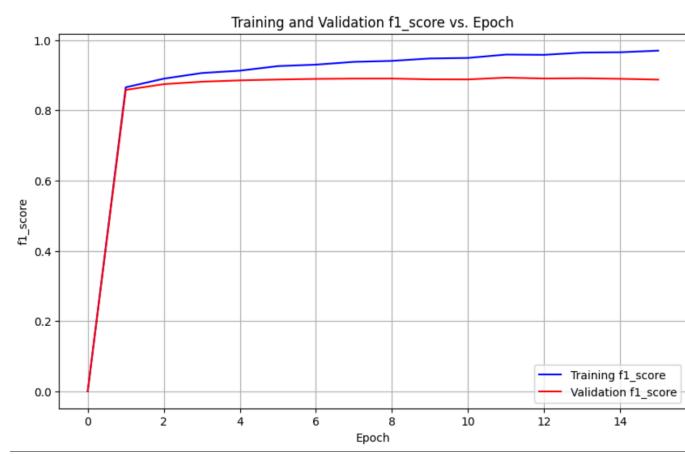
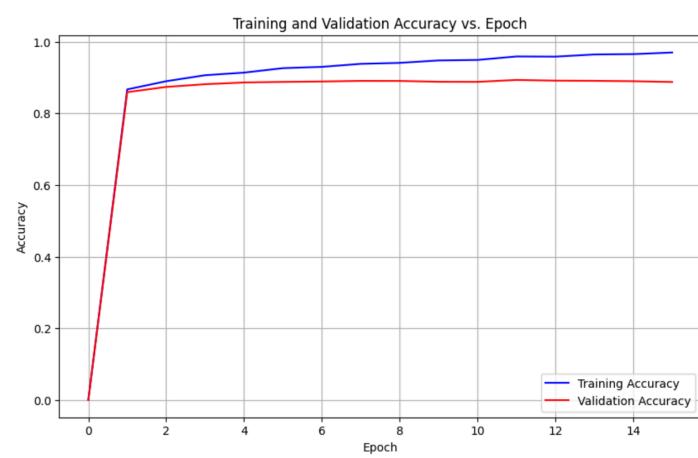
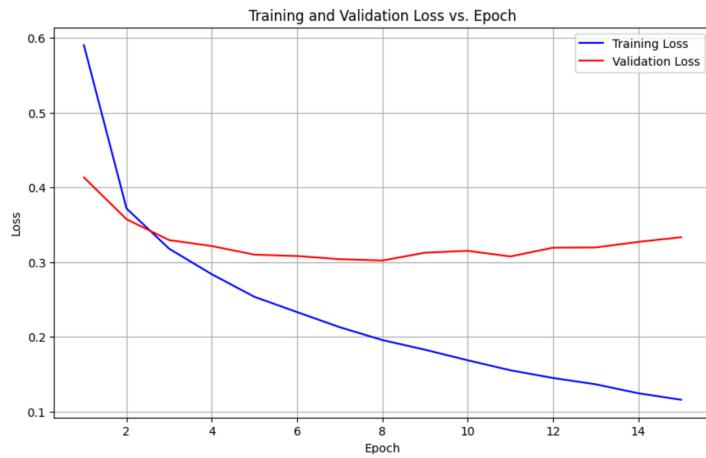
Validation Accuracy: 88.78%

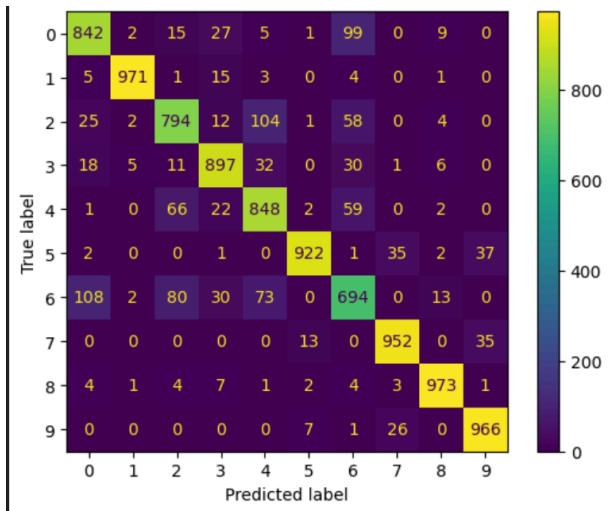
Validation f1_score: 88.78%

Test loss: 0.36098416872836614

Test Accuracy: 88.59%

Test f1_score: 88.55975840503592%



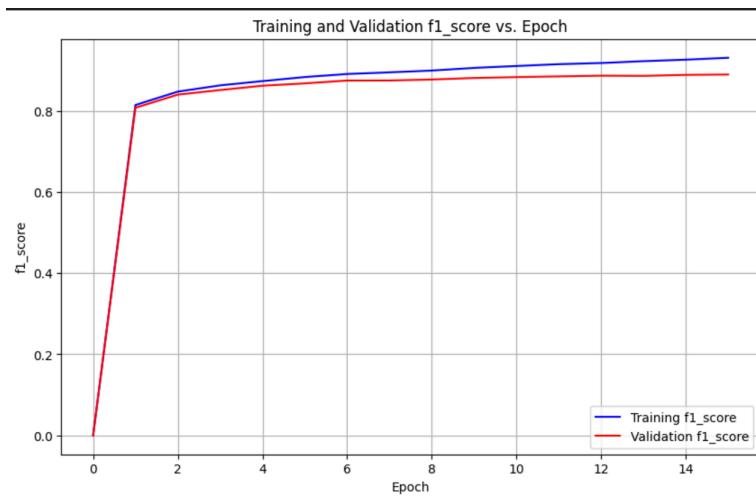
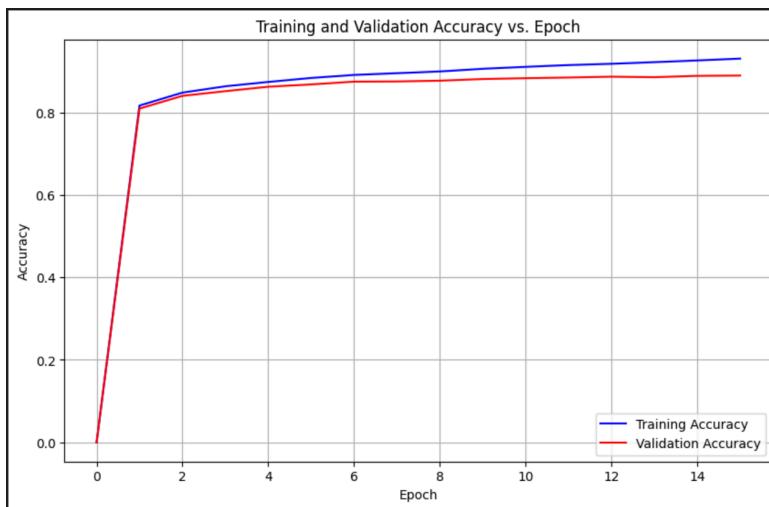
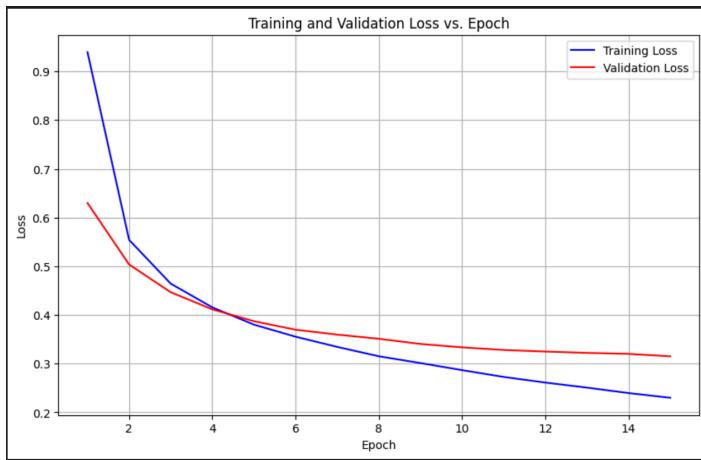


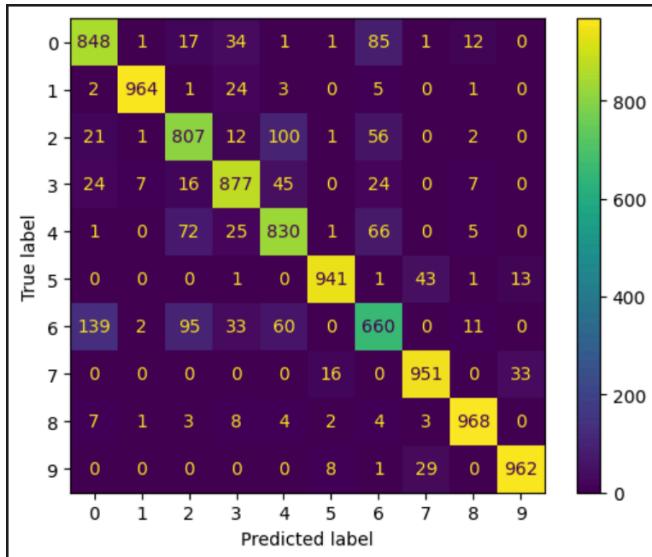
Hyperparameters: **Learning rate: alpha = 0.0001**, Batch Size: 256, Epoch = 15

Validation Loss: 0.3151156122896041
Validation Accuracy: 88.98%
Validation f1_score: 88.94%

Test loss: 0.3442504664002039
Test Accuracy: 88.08%
Test f1_score: 88.02746739796238%

```
Epoch 1, Training Loss: 0.939548947443449 Training Accuracy: 0.8168958333333334%
Validation Loss: 0.6298435385949477 Validation Accuracy: 80.96% Validation f1_score: 80.75%
100%|██████| 188/188 [00:02<00:00, 88.14it/s]
Epoch 2, Training Loss: 0.5541089712429613 Training Accuracy: 0.8482708333333333%
Validation Loss: 0.5035478134535394 Validation Accuracy: 84.05% Validation f1_score: 83.98%
100%|██████| 188/188 [00:02<00:00, 84.40it/s]
Epoch 3, Training Loss: 0.4642080747511095 Training Accuracy: 0.8636458333333333%
Validation Loss: 0.4465901615572783 Validation Accuracy: 85.18% Validation f1_score: 85.11%
100%|██████| 188/188 [00:02<00:00, 84.75it/s]
Epoch 4, Training Loss: 0.4154707058087007 Training Accuracy: 0.8741666666666666%
Validation Loss: 0.41147109741850607 Validation Accuracy: 86.26% Validation f1_score: 86.18%
100%|██████| 188/188 [00:02<00:00, 67.61it/s]
Epoch 5, Training Loss: 0.38006239476133236 Training Accuracy: 0.883875%
Validation Loss: 0.38704869063521374 Validation Accuracy: 86.82% Validation f1_score: 86.75%
100%|██████| 188/188 [00:02<00:00, 83.38it/s]
Epoch 6, Training Loss: 0.3552774632911994 Training Accuracy: 0.8911875%
Validation Loss: 0.3696710053110987 Validation Accuracy: 87.49% Validation f1_score: 87.46%
100%|██████| 188/188 [00:02<00:00, 70.60it/s]
Epoch 7, Training Loss: 0.33437677089972073 Training Accuracy: 0.8954375%
Validation Loss: 0.3595802827486247 Validation Accuracy: 87.54% Validation f1_score: 87.47%
100%|██████| 188/188 [00:02<00:00, 68.65it/s]
Epoch 8, Training Loss: 0.31508901041750803 Training Accuracy: 0.899625%
Validation Loss: 0.35103479748051564 Validation Accuracy: 87.72% Validation f1_score: 87.70%
100%|██████| 188/188 [00:02<00:00, 81.32it/s]
Epoch 9, Training Loss: 0.30119191735495965 Training Accuracy: 0.9061041666666667%
Validation Loss: 0.340409930681752 Validation Accuracy: 88.12% Validation f1_score: 88.09%
100%|██████| 188/188 [00:02<00:00, 74.18it/s]
Epoch 10, Training Loss: 0.2866684899427203 Training Accuracy: 0.9108333333333334%
Validation Loss: 0.3334862259923636 Validation Accuracy: 88.33% Validation f1_score: 88.30%
100%|██████| 188/188 [00:02<00:00, 79.58it/s]
Epoch 11, Training Loss: 0.2727034044784782 Training Accuracy: 0.915125%
Validation Loss: 0.3280269052314748 Validation Accuracy: 88.49% Validation f1_score: 88.48%
100%|██████| 188/188 [00:02<00:00, 71.34it/s]
Epoch 12, Training Loss: 0.261105553667179 Training Accuracy: 0.9182083333333333%
Validation Loss: 0.3248312937730222 Validation Accuracy: 88.69% Validation f1_score: 88.65%
100%|██████| 188/188 [00:02<00:00, 83.04it/s]
Epoch 13, Training Loss: 0.2507722498458193 Training Accuracy: 0.9221875%
Validation Loss: 0.3220838838779488 Validation Accuracy: 88.57% Validation f1_score: 88.61%
100%|██████| 188/188 [00:02<00:00, 73.93it/s]
Epoch 14, Training Loss: 0.23954632651026228 Training Accuracy: 0.9263333333333333%
Validation Loss: 0.3199923139072901 Validation Accuracy: 88.90% Validation f1_score: 88.85%
100%|██████| 188/188 [00:02<00:00, 70.49it/s]
Epoch 15, Training Loss: 0.22991645120942722 Training Accuracy: 0.9308125%
Validation Loss: 0.3151156122896041 Validation Accuracy: 88.98% Validation f1 score: 88.94%
```





Model Architecture - 2:

```

NeuralNetwork.add_layer(Dense(784, 1024))
NeuralNetwork.add_layer(BatchNormalization(1024))
NeuralNetwork.add_layer(ActivationLayer('Relu'))
NeuralNetwork.add_layer(Dense(1024, 256))
NeuralNetwork.add_layer(BatchNormalization(256))
NeuralNetwork.add_layer(ActivationLayer('Relu'))
NeuralNetwork.add_layer(Dense(256, 64))
NeuralNetwork.add_layer(BatchNormalization(64))
NeuralNetwork.add_layer(ActivationLayer('Relu'))
NeuralNetwork.add_layer(Dense(64, total_class))
NeuralNetwork.add_layer(ActivationLayer('Softmax'))

```

Hyperparameters: Learning rate: alpha = 0.005, Batch Size: 256, Epoch = 15

Validation Loss: 0.32661403457910015

Validation Accuracy: 89.70%

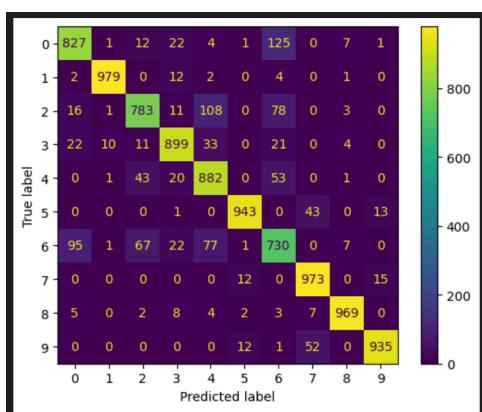
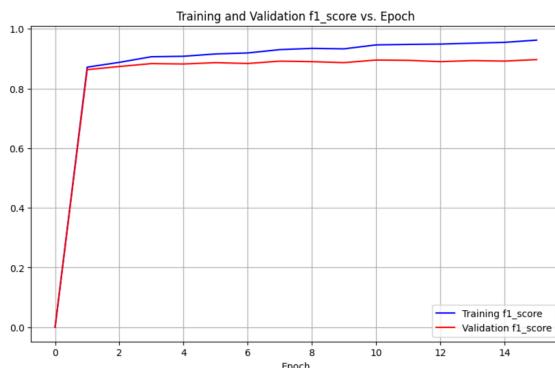
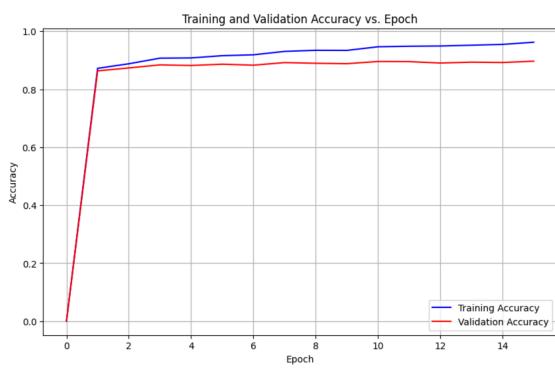
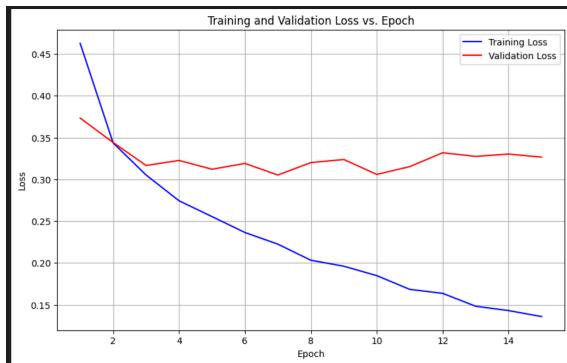
Validation f1_score: 89.71%

Test loss: 0.36796352675347427

Test Accuracy: 89.2%

Test f1_score: 89.21362372584612%

```
Epoch 1, Training Loss: 0.4627424713528087 Training Accuracy: 0.8723333333333333%
Validation Loss: 0.37335615829484226 Validation Accuracy: 86.36% Validation f1_score: 86.34%
100%|██████████| 188/188 [00:22<00:00, 8.51it/s]
Epoch 2, Training Loss: 0.34363498752227567 Training Accuracy: 0.8880416666666666%
Validation Loss: 0.34416447124708194 Validation Accuracy: 87.37% Validation f1_score: 87.39%
100%|██████████| 188/188 [00:20<00:00, 9.09it/s]
Epoch 3, Training Loss: 0.30525997699198204 Training Accuracy: 0.9073958333333333%
Validation Loss: 0.3166178378976071 Validation Accuracy: 88.42% Validation f1_score: 88.37%
100%|██████████| 188/188 [00:20<00:00, 9.07it/s]
Epoch 4, Training Loss: 0.2744384085322253 Training Accuracy: 0.9082291666666666%
Validation Loss: 0.3226744707065118 Validation Accuracy: 88.22% Validation f1_score: 88.24%
100%|██████████| 188/188 [00:20<00:00, 9.14it/s]
Epoch 5, Training Loss: 0.25551402061451944 Training Accuracy: 0.9160208333333333%
Validation Loss: 0.31216382544423676 Validation Accuracy: 88.66% Validation f1_score: 88.68%
100%|██████████| 188/188 [00:21<00:00, 8.90it/s]
Epoch 6, Training Loss: 0.2364560736796696 Training Accuracy: 0.9189583333333333%
Validation Loss: 0.319102109753155 Validation Accuracy: 88.33% Validation f1_score: 88.40%
100%|██████████| 188/188 [00:29<00:00, 6.33it/s]
Epoch 7, Training Loss: 0.2225171357028687 Training Accuracy: 0.9307916666666667%
Validation Loss: 0.3051919241381418 Validation Accuracy: 89.21% Validation f1_score: 89.19%
100%|██████████| 188/188 [00:27<00:00, 6.80it/s]
Epoch 8, Training Loss: 0.20328376402902082 Training Accuracy: 0.9345416666666667%
Validation Loss: 0.32009145378631126 Validation Accuracy: 88.98% Validation f1_score: 89.02%
100%|██████████| 188/188 [00:21<00:00, 8.80it/s]
Epoch 9, Training Loss: 0.19613825554095177 Training Accuracy: 0.9342083333333333%
Validation Loss: 0.3237927231348458 Validation Accuracy: 88.84% Validation f1_score: 88.69%
100%|██████████| 188/188 [00:20<00:00, 9.37it/s]
Epoch 10, Training Loss: 0.18489592103679825 Training Accuracy: 0.946708333333334%
Validation Loss: 0.3059333673986801 Validation Accuracy: 89.59% Validation f1_score: 89.56%
100%|██████████| 188/188 [00:20<00:00, 9.03it/s]
Epoch 11, Training Loss: 0.168444847590271197 Training Accuracy: 0.9485416666666666%
Validation Loss: 0.31527548487045276 Validation Accuracy: 89.55% Validation f1_score: 89.46%
100%|██████████| 188/188 [00:22<00:00, 8.45it/s]
Epoch 12, Training Loss: 0.16368076921014366 Training Accuracy: 0.949375%
Validation Loss: 0.3318490874968141 Validation Accuracy: 89.06% Validation f1_score: 89.02%
100%|██████████| 188/188 [00:21<00:00, 8.70it/s]
Epoch 13, Training Loss: 0.14827374576412908 Training Accuracy: 0.952145833333334%
Validation Loss: 0.32751571709061794 Validation Accuracy: 89.36% Validation f1_score: 89.37%
100%|██████████| 188/188 [00:26<00:00, 7.16it/s]
Epoch 14, Training Loss: 0.14305739945941343 Training Accuracy: 0.9549791666666667%
Validation Loss: 0.3303147060071558 Validation Accuracy: 89.24% Validation f1_score: 89.21%
100%|██████████| 188/188 [00:21<00:00, 8.91it/s]
Epoch 15, Training Loss: 0.13593236918875587 Training Accuracy: 0.9623958333333333%
Validation Loss: 0.32661403457910015 Validation Accuracy: 89.70% Validation f1_score: 89.71%
```

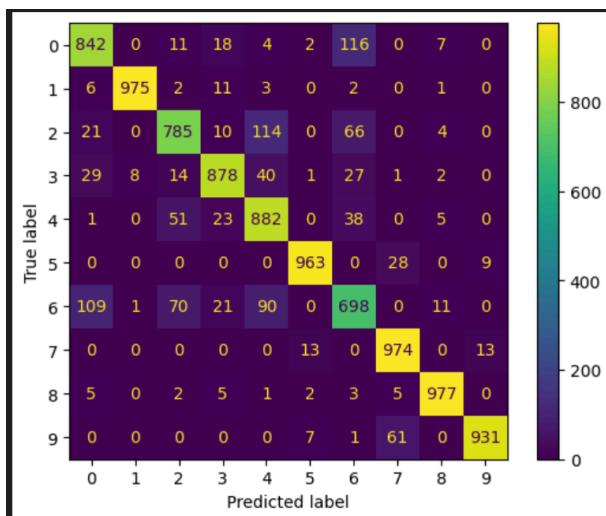
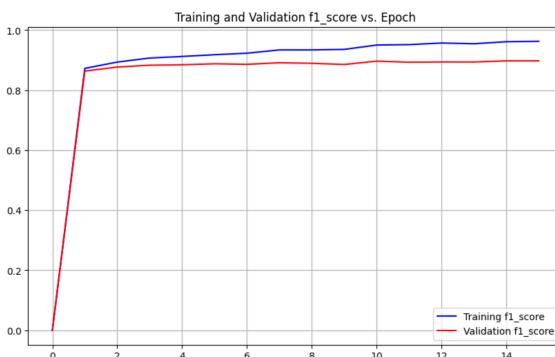
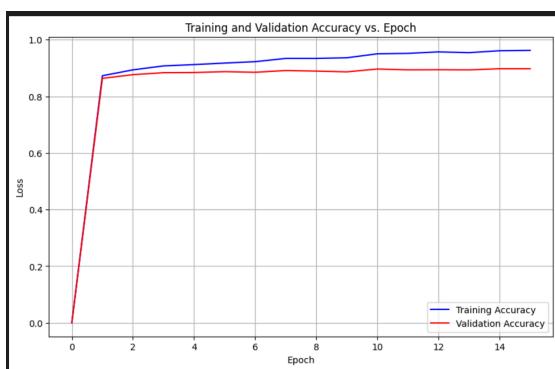
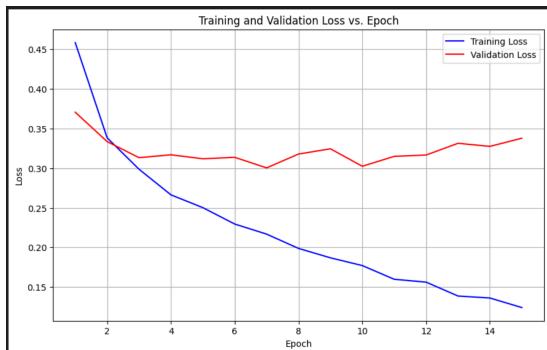


Hyperparameters: **Learning rate: alpha = 0.003**, Batch Size: 256, Epoch = 15

Validation Loss: 0.3377038315328667
Validation Accuracy: 89.77%
Validation f1_score: 89.75%

Test loss: 0.37980606465939776
Test Accuracy: 89.05%
Test f1_score: 89.03454029774748%

```
Epoch 1, Training Loss: 0.4582944571167812 Training Accuracy: 0.8729583333333333%
Validation Loss: 0.37051846742968314 Validation Accuracy: 86.37% Validation f1_score: 86.35%
100%|██████| 188/188 [00:21<00:00, 8.72it/s]
Epoch 2, Training Loss: 0.3382286789752131 Training Accuracy: 0.89375%
Validation Loss: 0.33346151971412363 Validation Accuracy: 87.67% Validation f1_score: 87.68%
100%|██████| 188/188 [00:30<00:00, 6.23it/s]
Epoch 3, Training Loss: 0.2985958810991381 Training Accuracy: 0.9076875%
Validation Loss: 0.3131944671930518 Validation Accuracy: 88.38% Validation f1_score: 88.30%
100%|██████| 188/188 [00:37<00:00, 5.01it/s]
Epoch 4, Training Loss: 0.266295495428201 Training Accuracy: 0.9123333333333333%
Validation Loss: 0.31679954420012335 Validation Accuracy: 88.43% Validation f1_score: 88.44%
100%|██████| 188/188 [00:36<00:00, 5.13it/s]
Epoch 5, Training Loss: 0.2501559039645149 Training Accuracy: 0.91775%
Validation Loss: 0.31181632536086545 Validation Accuracy: 88.74% Validation f1_score: 88.78%
100%|██████| 188/188 [00:28<00:00, 6.54it/s]
Epoch 6, Training Loss: 0.22947383805306024 Training Accuracy: 0.922625%
Validation Loss: 0.3136117190962187 Validation Accuracy: 88.52% Validation f1_score: 88.59%
100%|██████| 188/188 [00:21<00:00, 8.62it/s]
Epoch 7, Training Loss: 0.21675404331349293 Training Accuracy: 0.9341666666666667%
Validation Loss: 0.30030750416705626 Validation Accuracy: 89.14% Validation f1_score: 89.11%
100%|██████| 188/188 [00:20<00:00, 9.07it/s]
Epoch 8, Training Loss: 0.19873674525802545 Training Accuracy: 0.9341666666666667%
Validation Loss: 0.3177769148888411 Validation Accuracy: 88.93% Validation f1_score: 88.94%
100%|██████| 188/188 [00:20<00:00, 9.31it/s]
Epoch 9, Training Loss: 0.1868643809936978 Training Accuracy: 0.9364166666666667%
Validation Loss: 0.3243845638572279 Validation Accuracy: 88.67% Validation f1_score: 88.54%
100%|██████| 188/188 [00:21<00:00, 8.56it/s]
Epoch 10, Training Loss: 0.17709175319512468 Training Accuracy: 0.9504375%
Validation Loss: 0.3023452583812157 Validation Accuracy: 89.68% Validation f1_score: 89.65%
100%|██████| 188/188 [00:21<00:00, 8.65it/s]
Epoch 11, Training Loss: 0.15979653190119328 Training Accuracy: 0.9520208333333333%
Validation Loss: 0.3148284370782817 Validation Accuracy: 89.38% Validation f1_score: 89.30%
100%|██████| 188/188 [00:20<00:00, 9.12it/s]
Epoch 12, Training Loss: 0.15619635962303996 Training Accuracy: 0.9572083333333333%
Validation Loss: 0.3165248804586204 Validation Accuracy: 89.42% Validation f1_score: 89.38%
100%|██████| 188/188 [00:20<00:00, 8.96it/s]
Epoch 13, Training Loss: 0.1386815582281506 Training Accuracy: 0.9544791666666667%
Validation Loss: 0.3313149835560475 Validation Accuracy: 89.37% Validation f1_score: 89.36%
100%|██████| 188/188 [00:20<00:00, 9.31it/s]
Epoch 14, Training Loss: 0.1361797004436706 Training Accuracy: 0.961333333333334%
Validation Loss: 0.3274153866669168 Validation Accuracy: 89.77% Validation f1_score: 89.75%
100%|██████| 188/188 [00:19<00:00, 9.43it/s]
Epoch 15, Training Loss: 0.12412481038321478 Training Accuracy: 0.9625416666666666%
Validation Loss: 0.3377038315328667 Validation Accuracy: 89.77% Validation f1_score: 89.75%
```



BEST MODEL

Hyperparameters: **Learning rate: alpha = 0.0005**, Batch Size: 256, Epoch = 15

Validation Loss: 0.3341684499343266

Validation Accuracy: 89.98%

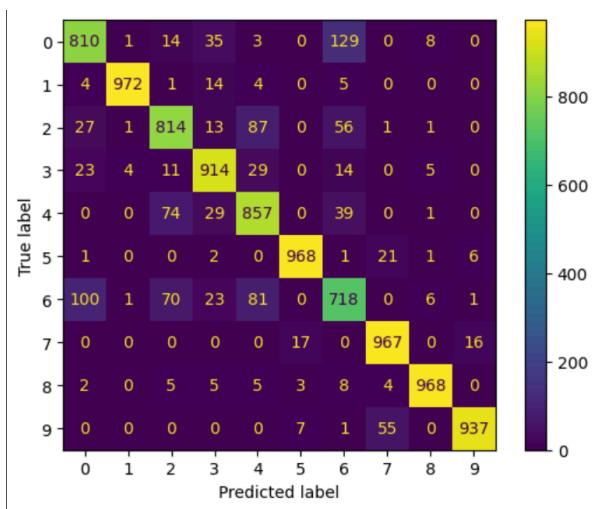
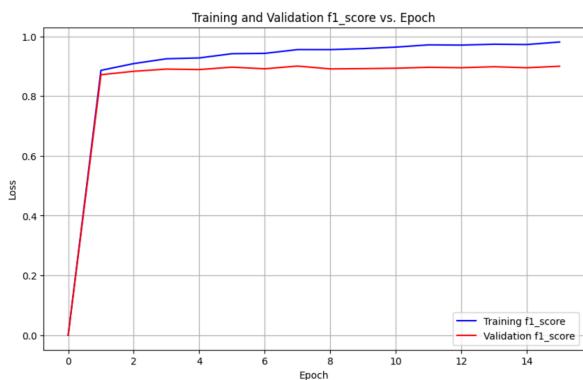
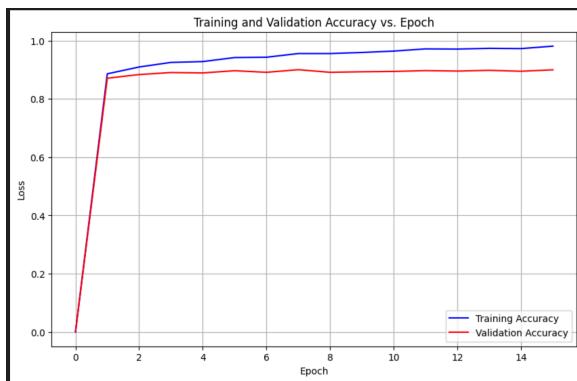
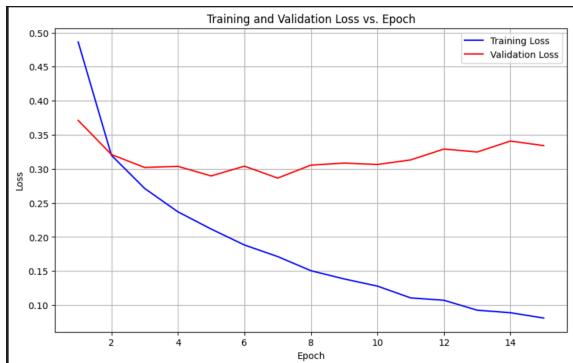
Validation f1_score: 89.99%

Test loss: 0.37274523584239566

Test Accuracy: 89.25%

Test f1_score: 89.24620793002866%

```
Epoch 1, Training Loss: 0.4863213825571696 Training Accuracy: 0.886%
Validation Loss: 0.37121133767845077 Validation Accuracy: 87.09% Validation f1_score: 87.15%
100%|██████████| 188/188 [00:20<00:00, 9.10it/s]
Epoch 2, Training Loss: 0.31994748363805176 Training Accuracy: 0.9094583333333334%
Validation Loss: 0.32106664971073984 Validation Accuracy: 88.35% Validation f1_score: 88.29%
100%|██████████| 188/188 [00:20<00:00, 8.97it/s]
Epoch 3, Training Loss: 0.27124715352014045 Training Accuracy: 0.9251666666666667%
Validation Loss: 0.30203521502236624 Validation Accuracy: 89.04% Validation f1_score: 89.03%
100%|██████████| 188/188 [00:20<00:00, 9.09it/s]
Epoch 4, Training Loss: 0.2369317064896788 Training Accuracy: 0.9280416666666667%
Validation Loss: 0.30371193100630645 Validation Accuracy: 88.91% Validation f1_score: 88.88%
100%|██████████| 188/188 [00:20<00:00, 9.02it/s]
Epoch 5, Training Loss: 0.211632725727992 Training Accuracy: 0.9418541666666667%
Validation Loss: 0.2896200419022281 Validation Accuracy: 89.67% Validation f1_score: 89.68%
100%|██████████| 188/188 [00:21<00:00, 8.81it/s]
Epoch 6, Training Loss: 0.1882560076507776 Training Accuracy: 0.9428958333333334%
Validation Loss: 0.3039668714070186 Validation Accuracy: 89.12% Validation f1_score: 89.14%
100%|██████████| 188/188 [00:20<00:00, 9.06it/s]
Epoch 7, Training Loss: 0.1712524471155378 Training Accuracy: 0.9556458333333333%
Validation Loss: 0.28646764631587024 Validation Accuracy: 90.02% Validation f1_score: 90.04%
100%|██████████| 188/188 [00:21<00:00, 8.94it/s]
Epoch 8, Training Loss: 0.1504911303879612 Training Accuracy: 0.9555833333333333%
Validation Loss: 0.3055208370353473 Validation Accuracy: 89.12% Validation f1_score: 89.10%
100%|██████████| 188/188 [00:21<00:00, 8.61it/s]
Epoch 9, Training Loss: 0.1384045790924149 Training Accuracy: 0.9592916666666667%
Validation Loss: 0.3084995335020496 Validation Accuracy: 89.30% Validation f1_score: 89.19%
100%|██████████| 188/188 [00:21<00:00, 8.70it/s]
Epoch 10, Training Loss: 0.12788673567239175 Training Accuracy: 0.9640625%
Validation Loss: 0.3064453291997555 Validation Accuracy: 89.42% Validation f1_score: 89.33%
100%|██████████| 188/188 [00:21<00:00, 8.64it/s]
Epoch 11, Training Loss: 0.11055276302284946 Training Accuracy: 0.9715833333333334%
Validation Loss: 0.3131708722694039 Validation Accuracy: 89.70% Validation f1_score: 89.63%
100%|██████████| 188/188 [00:22<00:00, 8.53it/s]
Epoch 12, Training Loss: 0.10710464907750465 Training Accuracy: 0.9709166666666667%
Validation Loss: 0.32912011620121684 Validation Accuracy: 89.54% Validation f1_score: 89.50%
100%|██████████| 188/188 [00:20<00:00, 9.02it/s]
Epoch 13, Training Loss: 0.09249731098156105 Training Accuracy: 0.9735416666666666%
Validation Loss: 0.32481631014703705 Validation Accuracy: 89.80% Validation f1_score: 89.82%
100%|██████████| 188/188 [00:21<00:00, 8.83it/s]
Epoch 14, Training Loss: 0.0888178580149328 Training Accuracy: 0.972625%
Validation Loss: 0.34085621149931294 Validation Accuracy: 89.48% Validation f1_score: 89.48%
100%|██████████| 188/188 [00:21<00:00, 8.82it/s]
Epoch 15, Training Loss: 0.08098106392278911 Training Accuracy: 0.9809791666666666%
Validation Loss: 0.3341684499343266 Validation Accuracy: 89.98% Validation f1_score: 89.99%
```



Hyperparameters: **Learning rate: alpha = 0.0001**, Batch Size: 256, Epoch = 15

Validation Loss: 0.3125098224970181

Validation Accuracy: 89.83%

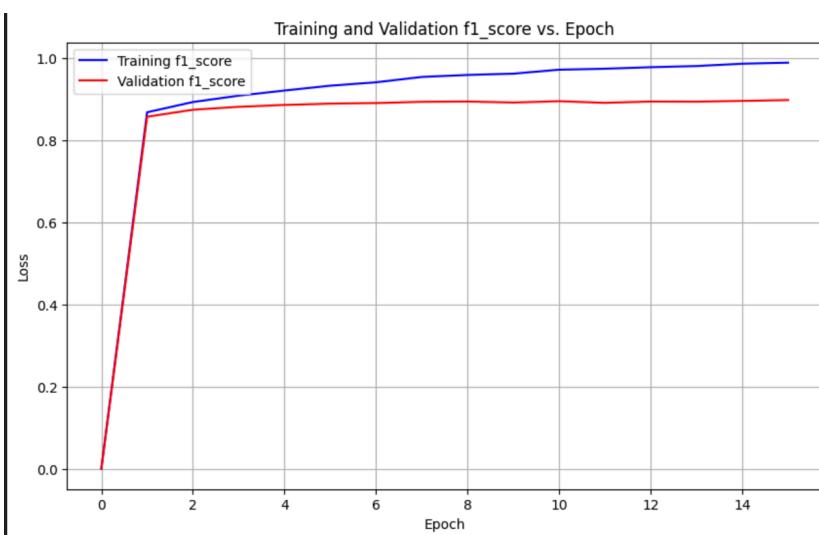
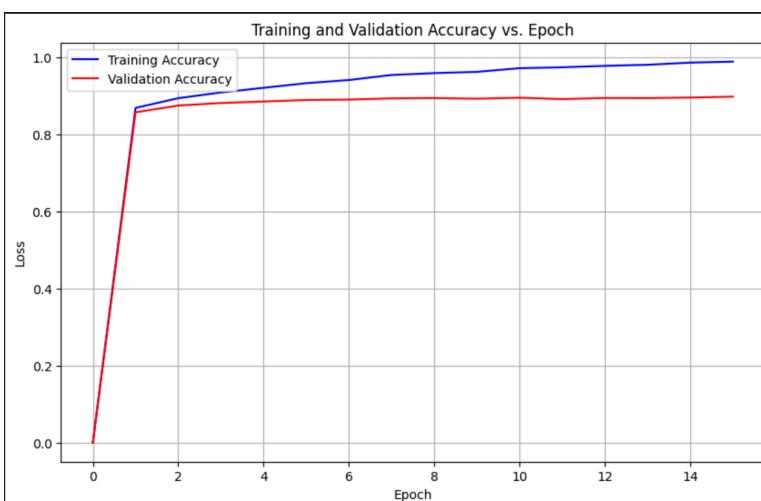
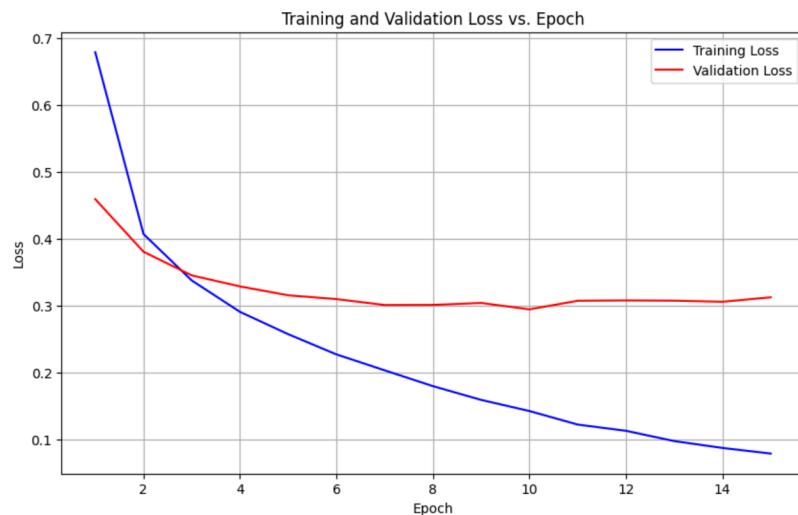
Validation f1_score: 89.81%

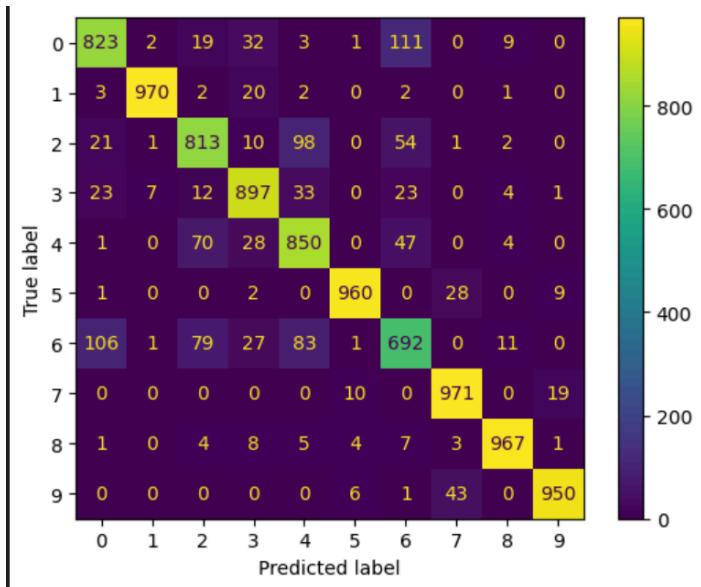
Test loss: 0.33990035910923805

Test Accuracy: 88.92999999999999%

Test f1_score: 88.90437525337884%

```
Epoch 1, Training Loss: 0.6791009117594288 Training Accuracy: 0.8689791666666666%
Validation Loss: 0.4592675496772144 Validation Accuracy: 85.77% Validation f1_score: 85.74%
100%|██████████| 188/188 [00:22<00:00, 8.47it/s]
Epoch 2, Training Loss: 0.4071078519408672 Training Accuracy: 0.8942708333333333%
Validation Loss: 0.38062405599294685 Validation Accuracy: 87.52% Validation f1_score: 87.45%
100%|██████████| 188/188 [00:20<00:00, 9.18it/s]
Epoch 3, Training Loss: 0.33769133160139253 Training Accuracy: 0.9090416666666666%
Validation Loss: 0.3452604384538662 Validation Accuracy: 88.17% Validation f1_score: 88.16%
100%|██████████| 188/188 [00:20<00:00, 9.02it/s]
Epoch 4, Training Loss: 0.29067078043701433 Training Accuracy: 0.9212291666666667%
Validation Loss: 0.3287788835167498 Validation Accuracy: 88.57% Validation f1_score: 88.62%
100%|██████████| 188/188 [00:20<00:00, 9.00it/s]
Epoch 5, Training Loss: 0.25728054752021556 Training Accuracy: 0.9332083333333333%
Validation Loss: 0.3154613357529808 Validation Accuracy: 88.95% Validation f1_score: 88.94%
100%|██████████| 188/188 [00:20<00:00, 9.02it/s]
Epoch 6, Training Loss: 0.22703312030888198 Training Accuracy: 0.9414166666666667%
Validation Loss: 0.3097863358544761 Validation Accuracy: 89.07% Validation f1_score: 89.08%
100%|██████████| 188/188 [00:20<00:00, 9.18it/s]
Epoch 7, Training Loss: 0.20320269766579144 Training Accuracy: 0.9545208333333334%
Validation Loss: 0.3009421691647559 Validation Accuracy: 89.39% Validation f1_score: 89.39%
100%|██████████| 188/188 [00:21<00:00, 8.55it/s]
Epoch 8, Training Loss: 0.1795830977093628 Training Accuracy: 0.9593541666666666%
Validation Loss: 0.3010864352900677 Validation Accuracy: 89.46% Validation f1_score: 89.45%
100%|██████████| 188/188 [00:21<00:00, 8.83it/s]
Epoch 9, Training Loss: 0.1589898139114936 Training Accuracy: 0.962625%
Validation Loss: 0.3040112478755727 Validation Accuracy: 89.30% Validation f1_score: 89.21%
100%|██████████| 188/188 [00:22<00:00, 8.33it/s]
Epoch 10, Training Loss: 0.14234878248433425 Training Accuracy: 0.9721458333333334%
Validation Loss: 0.29444931510279365 Validation Accuracy: 89.54% Validation f1_score: 89.53%
100%|██████████| 188/188 [00:21<00:00, 8.86it/s]
Epoch 11, Training Loss: 0.12209904081413026 Training Accuracy: 0.9744791666666667%
Validation Loss: 0.3073008317931006 Validation Accuracy: 89.19% Validation f1_score: 89.14%
100%|██████████| 188/188 [00:21<00:00, 8.82it/s]
Epoch 12, Training Loss: 0.11280311977618898 Training Accuracy: 0.9782083333333333%
Validation Loss: 0.30781935637269614 Validation Accuracy: 89.48% Validation f1_score: 89.45%
100%|██████████| 188/188 [00:23<00:00, 8.03it/s]
Epoch 13, Training Loss: 0.09742737591579159 Training Accuracy: 0.981%
Validation Loss: 0.30741453582998894 Validation Accuracy: 89.44% Validation f1_score: 89.41%
100%|██████████| 188/188 [00:21<00:00, 8.85it/s]
Epoch 14, Training Loss: 0.08714198116141261 Training Accuracy: 0.9866041666666666%
Validation Loss: 0.30578174848015277 Validation Accuracy: 89.59% Validation f1_score: 89.61%
100%|██████████| 188/188 [00:20<00:00, 9.05it/s]
Epoch 15, Training Loss: 0.07874418151932497 Training Accuracy: 0.9891458333333333%
Validation Loss: 0.3125098224970181 Validation Accuracy: 89.83% Validation f1_score: 89.81%
```





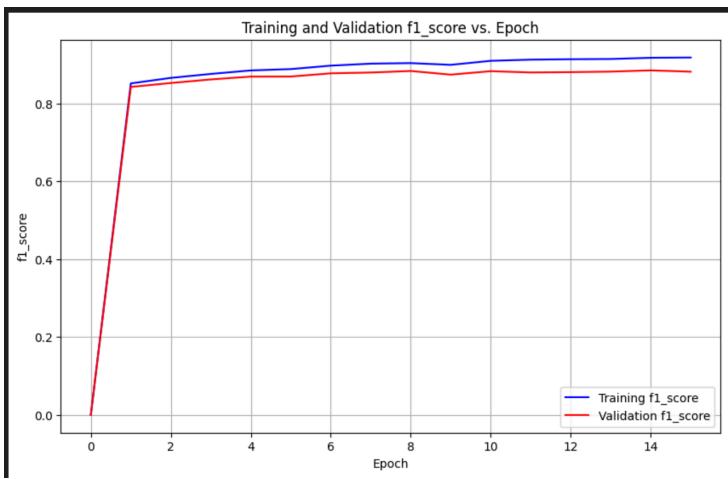
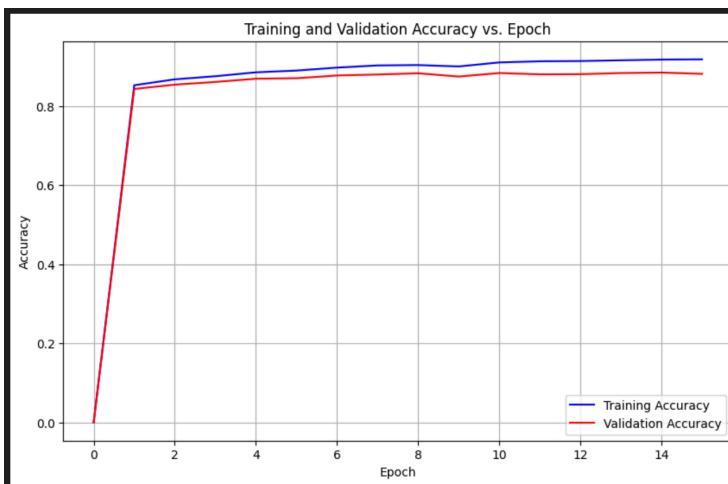
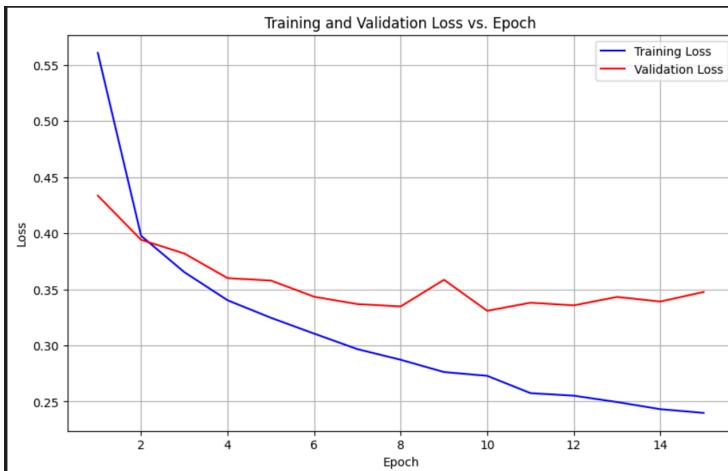
```
NeuralNetwork.add_layer(Dense(784, 512))
NeuralNetwork.add_layer(BatchNormalization(512))
NeuralNetwork.add_layer(ActivationLayer('Relu'))
NeuralNetwork.add_layer(Dropout(0.3))
NeuralNetwork.add_layer(Dense(512, 128))
NeuralNetwork.add_layer(BatchNormalization(128))
NeuralNetwork.add_layer(ActivationLayer('Relu'))
NeuralNetwork.add_layer(Dropout(0.3))
NeuralNetwork.add_layer(Dense(128, 32))
NeuralNetwork.add_layer(BatchNormalization(32))
NeuralNetwork.add_layer(ActivationLayer('Relu'))
NeuralNetwork.add_layer(Dense(32, total_class))
NeuralNetwork.add_layer(ActivationLayer('Softmax'))
```

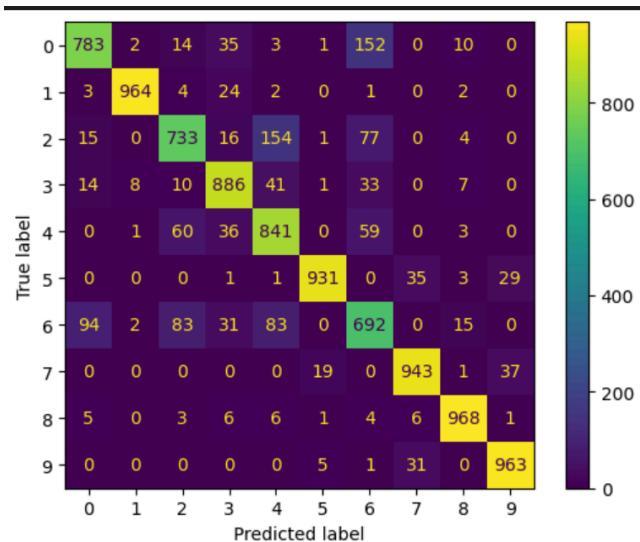
Hyperparameters: Learning rate: alpha = 0.005, Batch Size: 256, Epoch = 15

```
Validation Loss: 0.34765108621662943
Validation Accuracy: 88.11%
Validation f1_score: 88.15%

Test loss: 0.3673283099440905
Test Accuracy: 87.15%
Test f1_score: 87.17963476614766%
```

```
Epoch 1, Training Loss: 0.3667110504370974 Training Accuracy: 0.8525125%
Validation Loss: 0.43347976984902614 Validation Accuracy: 84.29% Validation f1_score: 84.23%
100%[██████] 188/188 [00:09<00:00, 20.43it/s]
Epoch 2, Training Loss: 0.397659898392225 Training Accuracy: 0.8672916666666667%
Validation Loss: 0.39414299205383 Validation Accuracy: 85.38% Validation f1_score: 85.24%
100%[██████] 188/188 [00:08<00:00, 21.23it/s]
Epoch 3, Training Loss: 0.36527634631560263 Training Accuracy: 0.8751458333333333%
Validation Loss: 0.38189044616686657 Validation Accuracy: 86.07% Validation f1_score: 86.16%
100%[██████] 188/188 [00:08<00:00, 21.23it/s]
Epoch 4, Training Loss: 0.34022377446289126 Training Accuracy: 0.885%
Validation Loss: 0.35997988961430444 Validation Accuracy: 86.88% Validation f1_score: 86.88%
100%[██████] 188/188 [00:08<00:00, 21.32it/s]
Epoch 5, Training Loss: 0.3246424857845868 Training Accuracy: 0.8894166666666666%
Validation Loss: 0.3578186869745081 Validation Accuracy: 87.01% Validation f1_score: 86.90%
100%[██████] 188/188 [00:08<00:00, 21.51it/s]
Epoch 6, Training Loss: 0.3105204600179683 Training Accuracy: 0.8969166666666667%
Validation Loss: 0.3433840155271718 Validation Accuracy: 87.70% Validation f1_score: 87.72%
100%[██████] 188/188 [00:08<00:00, 22.41it/s]
Epoch 7, Training Loss: 0.29668484404556333 Training Accuracy: 0.9024166666666666%
Validation Loss: 0.3368360986284687 Validation Accuracy: 87.95% Validation f1_score: 87.93%
100%[██████] 188/188 [00:08<00:00, 22.57it/s]
Epoch 8, Training Loss: 0.28720819981330764 Training Accuracy: 0.9033541666666667%
Validation Loss: 0.33475354184072564 Validation Accuracy: 88.26% Validation f1_score: 88.33%
100%[██████] 188/188 [00:08<00:00, 21.33it/s]
Epoch 9, Training Loss: 0.27628235744000174 Training Accuracy: 0.899833333333334%
Validation Loss: 0.3584929876287979 Validation Accuracy: 87.43% Validation f1_score: 87.39%
100%[██████] 188/188 [00:08<00:00, 21.71it/s]
Epoch 10, Training Loss: 0.2728960048825641 Training Accuracy: 0.91%
Validation Loss: 0.3308434397976789 Validation Accuracy: 88.32% Validation f1_score: 88.28%
100%[██████] 188/188 [00:09<00:00, 20.69it/s]
Epoch 11, Training Loss: 0.2574713775906857 Training Accuracy: 0.912895833333334%
Validation Loss: 0.3380791929388268 Validation Accuracy: 87.99% Validation f1_score: 87.95%
100%[██████] 188/188 [00:07<00:00, 24.66it/s]
Epoch 12, Training Loss: 0.25521128254139225 Training Accuracy: 0.913458333333334%
Validation Loss: 0.33570512333444563 Validation Accuracy: 88.03% Validation f1_score: 88.03%
100%[██████] 188/188 [00:09<00:00, 20.55it/s]
Epoch 13, Training Loss: 0.24953570061980482 Training Accuracy: 0.9154166666666667%
Validation Loss: 0.34322503158061507 Validation Accuracy: 88.31% Validation f1_score: 88.16%
100%[██████] 188/188 [00:09<00:00, 20.39it/s]
Epoch 14, Training Loss: 0.2431710334179343 Training Accuracy: 0.9171458333333333%
Validation Loss: 0.3391064501205811 Validation Accuracy: 88.44% Validation f1_score: 88.49%
100%[██████] 188/188 [00:09<00:00, 19.78it/s]
Epoch 15, Training Loss: 0.2398600145544936 Training Accuracy: 0.9177916666666667%
Validation Loss: 0.34765108621662943 Validation Accuracy: 88.11% Validation f1_score: 88.15%
```





Hyperparameters: **Learning rate: alpha = 0.001**, Batch Size: 256, Epoch = 15

Validation Loss: 0.34174739549149785

Validation Accuracy: 88.27%

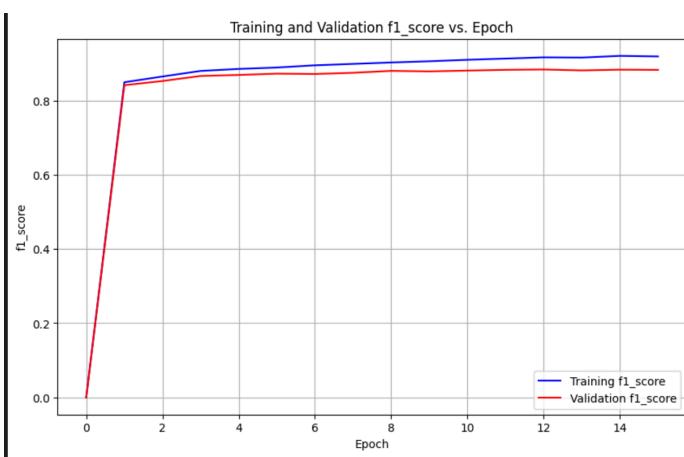
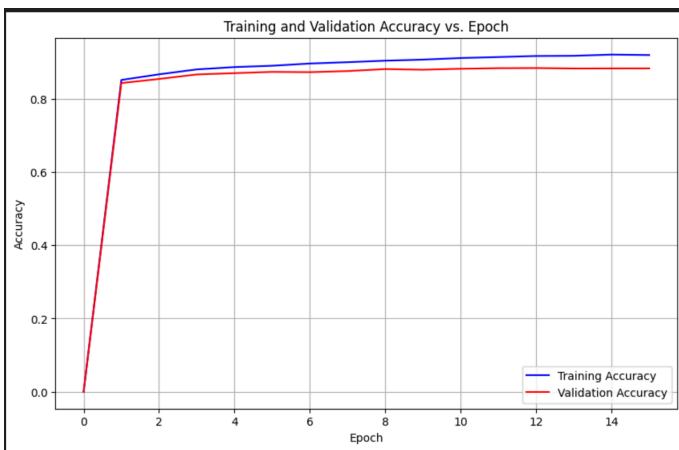
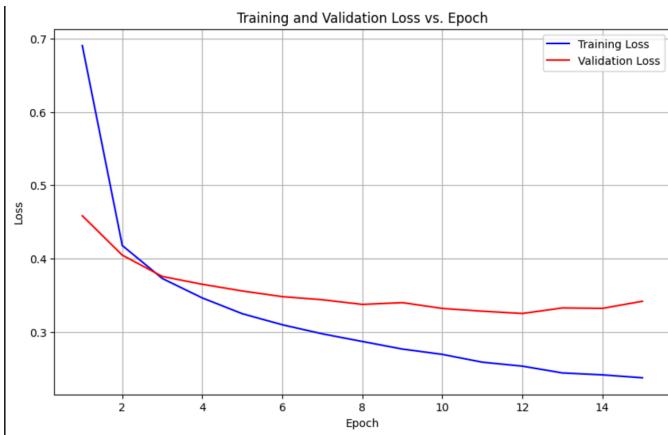
Validation f1_score: 88.28%

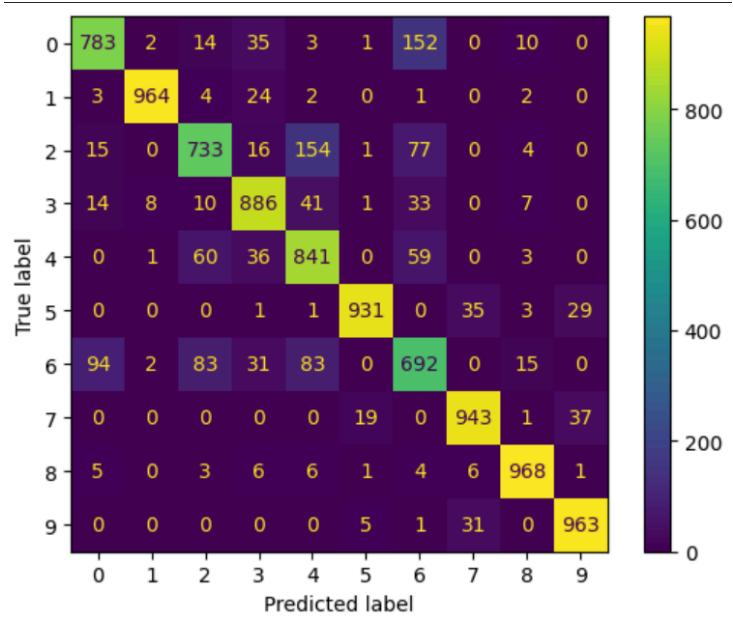
Test loss: 0.37123163911321355

Test Accuracy: 87.03999999999999%

Test f1_score: 87.04676043718023%

```
Epoch 1, Training Loss: 0.6904012084923369 Training Accuracy: 0.8510208333333333%
Validation Loss: 0.45832838611049237 Validation Accuracy: 84.27% Validation f1_score: 84.15%
100%|██████████| 188/188 [00:17<00:00, 10.56it/s]
Epoch 2, Training Loss: 0.4177277546706176 Training Accuracy: 0.8664375%
Validation Loss: 0.4045957315515549 Validation Accuracy: 85.38% Validation f1_score: 85.28%
100%|██████████| 188/188 [00:13<00:00, 13.68it/s]
Epoch 3, Training Loss: 0.3727957604325263 Training Accuracy: 0.879833333333334%
Validation Loss: 0.37557776246957186 Validation Accuracy: 86.61% Validation f1_score: 86.64%
100%|██████████| 188/188 [00:13<00:00, 14.03it/s]
Epoch 4, Training Loss: 0.3462479274658141 Training Accuracy: 0.8862291666666666%
Validation Loss: 0.3648903227811235 Validation Accuracy: 86.97% Validation f1_score: 86.92%
100%|██████████| 188/188 [00:15<00:00, 12.04it/s]
Epoch 5, Training Loss: 0.32474445974948085 Training Accuracy: 0.889833333333334%
Validation Loss: 0.3557717307470468 Validation Accuracy: 87.31% Validation f1_score: 87.26%
100%|██████████| 188/188 [00:12<00:00, 15.05it/s]
Epoch 6, Training Loss: 0.30968417564514966 Training Accuracy: 0.8958958333333333%
Validation Loss: 0.3480363747019352 Validation Accuracy: 87.23% Validation f1_score: 87.17%
100%|██████████| 188/188 [00:14<00:00, 12.89it/s]
Epoch 7, Training Loss: 0.2973273397313711 Training Accuracy: 0.8995416666666667%
Validation Loss: 0.34382337305836197 Validation Accuracy: 87.53% Validation f1_score: 87.49%
100%|██████████| 188/188 [00:11<00:00, 15.92it/s]
Epoch 8, Training Loss: 0.2868823658521069 Training Accuracy: 0.903645833333334%
Validation Loss: 0.33740902697503894 Validation Accuracy: 88.08% Validation f1_score: 88.02%
100%|██████████| 188/188 [00:08<00:00, 22.44it/s]
Epoch 9, Training Loss: 0.2765651180560754 Training Accuracy: 0.9065833333333333%
Validation Loss: 0.33985534600480494 Validation Accuracy: 87.90% Validation f1_score: 87.87%
100%|██████████| 188/188 [00:07<00:00, 25.03it/s]
Epoch 10, Training Loss: 0.269282095195881 Training Accuracy: 0.9109166666666667%
Validation Loss: 0.331956365309062 Validation Accuracy: 88.16% Validation f1_score: 88.09%
100%|██████████| 188/188 [00:07<00:00, 23.87it/s]
Epoch 11, Training Loss: 0.2586146020043268 Training Accuracy: 0.9136041666666667%
Validation Loss: 0.32820166299303805 Validation Accuracy: 88.33% Validation f1_score: 88.30%
100%|██████████| 188/188 [00:10<00:00, 17.76it/s]
Epoch 12, Training Loss: 0.2532640218306711 Training Accuracy: 0.9164375%
Validation Loss: 0.3250541337644994 Validation Accuracy: 88.36% Validation f1_score: 88.39%
100%|██████████| 188/188 [00:08<00:00, 21.80it/s]
Epoch 13, Training Loss: 0.24399029662885768 Training Accuracy: 0.9169791666666667%
Validation Loss: 0.33265971299009806 Validation Accuracy: 88.24% Validation f1_score: 88.14%
100%|██████████| 188/188 [00:07<00:00, 23.71it/s]
Epoch 14, Training Loss: 0.24137182016535144 Training Accuracy: 0.92025%
Validation Loss: 0.33203750591281483 Validation Accuracy: 88.26% Validation f1_score: 88.34%
100%|██████████| 188/188 [00:07<00:00, 24.31it/s]
Epoch 15, Training Loss: 0.23738457905981236 Training Accuracy: 0.9190416666666666%
Validation Loss: 0.34174739549149785 Validation Accuracy: 88.27% Validation f1_score: 88.28%
```



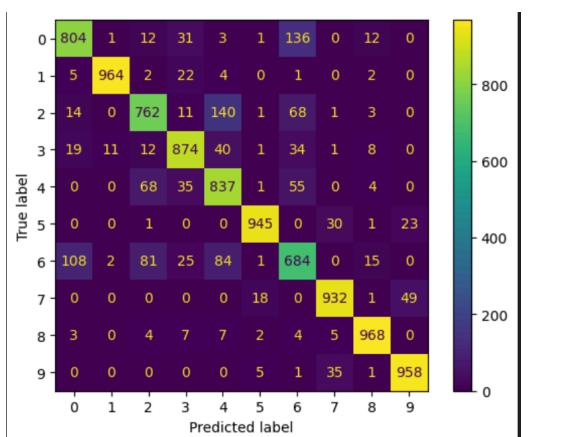
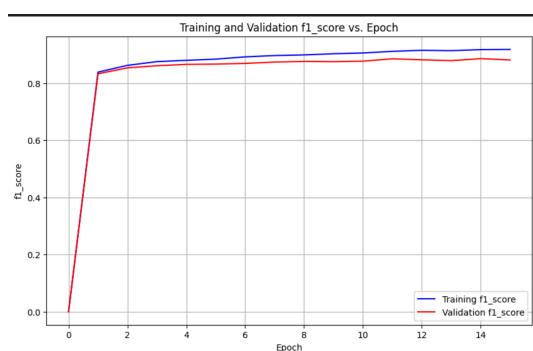
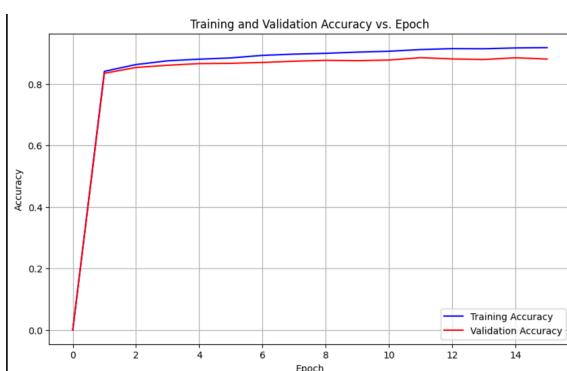
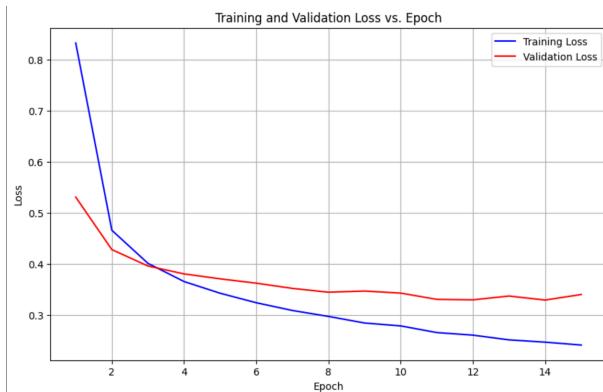


Hyperparameters: **Learning rate: alpha = 0.0005**, Batch Size: 256, Epoch = 15

```
Validation Loss: 0.34064131646998985
Validation Accuracy: 88.07%
Validation f1_score: 88.08%
```

```
Test loss: 0.3697961759663393
Test Accuracy: 87.28%
Test f1_score: 87.27740425448684%
```

```
Epoch 1, Training Loss: 0.8329371255924982 Training Accuracy: 0.8407708333333334%
Validation Loss: 0.5312691112109977 Validation Accuracy: 83.44% Validation f1_score: 83.25%
100%|██████████| 188/188 [00:16<00:00, 11.17it/s]
Epoch 2, Training Loss: 0.466417920178329 Training Accuracy: 0.8628125%
Validation Loss: 0.4285136865431094 Validation Accuracy: 85.34% Validation f1_score: 85.32%
100%|██████████| 188/188 [00:12<00:00, 14.62it/s]
Epoch 3, Training Loss: 0.40162292311225595 Training Accuracy: 0.8749791666666666%
Validation Loss: 0.3964417772761372 Validation Accuracy: 86.05% Validation f1_score: 86.07%
100%|██████████| 188/188 [00:14<00:00, 12.79it/s]
Epoch 4, Training Loss: 0.3660000269047522 Training Accuracy: 0.8803541666666667%
Validation Loss: 0.38093810607600465 Validation Accuracy: 86.59% Validation f1_score: 86.55%
100%|██████████| 188/188 [00:12<00:00, 14.86it/s]
Epoch 5, Training Loss: 0.3431061379884206 Training Accuracy: 0.884395833333334%
Validation Loss: 0.3712989990151513 Validation Accuracy: 86.69% Validation f1_score: 86.64%
100%|██████████| 188/188 [00:14<00:00, 13.39it/s]
Epoch 6, Training Loss: 0.32452045881612385 Training Accuracy: 0.8926875%
Validation Loss: 0.3627895446658403 Validation Accuracy: 86.97% Validation f1_score: 86.88%
100%|██████████| 188/188 [00:12<00:00, 14.70it/s]
Epoch 7, Training Loss: 0.30937976369183595 Training Accuracy: 0.8967291666666667%
Validation Loss: 0.35260715822672106 Validation Accuracy: 87.37% Validation f1_score: 87.34%
100%|██████████| 188/188 [00:15<00:00, 12.33it/s]
Epoch 8, Training Loss: 0.2977378547231741 Training Accuracy: 0.8993125%
Validation Loss: 0.3451119491838157 Validation Accuracy: 87.65% Validation f1_score: 87.59%
100%|██████████| 188/188 [00:26<00:00, 7.15it/s]
Epoch 9, Training Loss: 0.2848326410031201 Training Accuracy: 0.9031875%
Validation Loss: 0.3474312944215007 Validation Accuracy: 87.53% Validation f1_score: 87.49%
100%|██████████| 188/188 [00:16<00:00, 11.14it/s]
Epoch 10, Training Loss: 0.27916910221329644 Training Accuracy: 0.9061041666666667%
Validation Loss: 0.34337961546627527 Validation Accuracy: 87.75% Validation f1_score: 87.67%
100%|██████████| 188/188 [00:14<00:00, 12.97it/s]
Epoch 11, Training Loss: 0.2661257154119225 Training Accuracy: 0.9115625%
Validation Loss: 0.3310944727472785 Validation Accuracy: 88.52% Validation f1_score: 88.49%
100%|██████████| 188/188 [00:16<00:00, 11.42it/s]
Epoch 12, Training Loss: 0.2611195406133772 Training Accuracy: 0.9146041666666667%
Validation Loss: 0.3302013626183561 Validation Accuracy: 88.12% Validation f1_score: 88.15%
100%|██████████| 188/188 [00:18<00:00, 10.40it/s]
Epoch 13, Training Loss: 0.251860321893114 Training Accuracy: 0.9141666666666667%
Validation Loss: 0.3376345034594504 Validation Accuracy: 87.92% Validation f1_score: 87.84%
100%|██████████| 188/188 [00:13<00:00, 14.22it/s]
Epoch 14, Training Loss: 0.2473438029782972 Training Accuracy: 0.9168541666666666%
Validation Loss: 0.329779104597115 Validation Accuracy: 88.49% Validation f1_score: 88.56%
100%|██████████| 188/188 [00:12<00:00, 14.94it/s]
Epoch 15, Training Loss: 0.24170481139859565 Training Accuracy: 0.9177916666666667%
Validation Loss: 0.34064131646998985 Validation Accuracy: 88.07% Validation f1_score: 88.08%
```



Hyperparameters: **Learning rate: alpha = 0.0001**, Batch Size: 256, Epoch = 15

Validation Loss: 0.3763944664371407

Validation Accuracy: 86.87%

Validation f1_score: 86.81%

Test loss: 0.4031496738455471

Test Accuracy: 86.02%

Test f1_score: 85.94760878991717%

```
Epoch 1, Training Loss: 1.366351180609203 Training Accuracy: 0.7582291666666666%
Validation Loss: 0.9806216656000829 Validation Accuracy: 75.81% Validation f1_score: 75.30%
100%|██████| 188/188 [00:06<00:00, 29.51it/s]
Epoch 2, Training Loss: 0.8379900905934968 Training Accuracy: 0.8100208333333333%
Validation Loss: 0.733759065229036 Validation Accuracy: 80.47% Validation f1_score: 80.30%
100%|██████| 188/188 [00:07<00:00, 24.82it/s]
Epoch 3, Training Loss: 0.6662035900203064 Training Accuracy: 0.8325833333333333%
Validation Loss: 0.6194164402071319 Validation Accuracy: 82.08% Validation f1_score: 81.95%
100%|██████| 188/188 [00:07<00:00, 26.59it/s]
Epoch 4, Training Loss: 0.5740933424669536 Training Accuracy: 0.8420416666666667%
Validation Loss: 0.5503001186472568 Validation Accuracy: 83.35% Validation f1_score: 83.25%
100%|██████| 188/188 [00:07<00:00, 23.77it/s]
Epoch 5, Training Loss: 0.5145965691229072 Training Accuracy: 0.8509375%
Validation Loss: 0.5009806418909908 Validation Accuracy: 83.94% Validation f1_score: 83.86%
100%|██████| 188/188 [00:07<00:00, 26.84it/s]
Epoch 6, Training Loss: 0.4746088901895436 Training Accuracy: 0.859125%
Validation Loss: 0.47226661442582735 Validation Accuracy: 84.85% Validation f1_score: 84.74%
100%|██████| 188/188 [00:07<00:00, 23.72it/s]
Epoch 7, Training Loss: 0.4432556615211136 Training Accuracy: 0.8639375%
Validation Loss: 0.4467815338014371 Validation Accuracy: 85.19% Validation f1_score: 85.11%
100%|██████| 188/188 [00:07<00:00, 24.94it/s]
Epoch 8, Training Loss: 0.42219133084529387 Training Accuracy: 0.8676875%
Validation Loss: 0.42828400814022605 Validation Accuracy: 85.82% Validation f1_score: 85.73%
100%|██████| 188/188 [00:08<00:00, 22.91it/s]
Epoch 9, Training Loss: 0.4038812293670777 Training Accuracy: 0.8706041666666666%
Validation Loss: 0.41722389475405514 Validation Accuracy: 85.72% Validation f1_score: 85.67%
100%|██████| 188/188 [00:07<00:00, 24.88it/s]
Epoch 10, Training Loss: 0.3867821628908942 Training Accuracy: 0.8751458333333333%
Validation Loss: 0.40481112419908105 Validation Accuracy: 85.81% Validation f1_score: 85.74%
100%|██████| 188/188 [00:08<00:00, 23.27it/s]
Epoch 11, Training Loss: 0.3701190070670735 Training Accuracy: 0.8781666666666667%
Validation Loss: 0.39124416827935327 Validation Accuracy: 86.34% Validation f1_score: 86.26%
100%|██████| 188/188 [00:08<00:00, 23.38it/s]
Epoch 12, Training Loss: 0.36102995353894746 Training Accuracy: 0.8815208333333333%
Validation Loss: 0.38901356692764044 Validation Accuracy: 86.58% Validation f1_score: 86.58%
100%|██████| 188/188 [00:07<00:00, 25.91it/s]
Epoch 13, Training Loss: 0.3515179662211894 Training Accuracy: 0.8868541666666667%
Validation Loss: 0.38400420719303596 Validation Accuracy: 86.79% Validation f1_score: 86.75%
100%|██████| 188/188 [00:07<00:00, 25.35it/s]
Epoch 14, Training Loss: 0.34368950999147896 Training Accuracy: 0.8871666666666667%
Validation Loss: 0.3763889387613872 Validation Accuracy: 86.75% Validation f1_score: 86.73%
100%|██████| 188/188 [00:07<00:00, 23.79it/s]
Epoch 15, Training Loss: 0.33454562895110085 Training Accuracy: 0.88825%
Validation Loss: 0.3763944664371407 Validation Accuracy: 86.87% Validation f1_score: 86.81%
```

