

# HW5 CS541 Report

Q1) Gradient updates over several epochs:

```
1 log_dir = "logs/fit/" + datetime.datetime.now().strftime("%Y%m%d-%H%M%S")
2 tensorboard_callback = TensorBoard(log_dir=log_dir, histogram_freq=1)
3 checkpointer = ModelCheckpoint(filepath='model.weights.best.hdf5', verbose=1, save_best_only=True)
4 model.fit(x_train,
5         y_train,
6         batch_size=64,
7         epochs=10,
8         validation_data=(x_valid, y_valid),
9         callbacks=[checkpointer, tensorboard_callback])
```

[9] Python

... Output exceeds the [size limit](#). Open the full output data [in a text editor](#)

Epoch 1/10  
859/860 [=====>.] - ETA: 0s - loss: 0.6101 - accuracy: 0.7749  
Epoch 1: val\_loss improved from inf to 0.39379, saving model to model.weights.best.hdf5  
860/860 [=====] - 51s 58ms/step - loss: 0.6100 - accuracy: 0.7749 - val\_loss: 0.3938 - val\_accuracy: 0.8572  
Epoch 2/10  
859/860 [=====>.] - ETA: 0s - loss: 0.4282 - accuracy: 0.8456  
Epoch 2: val\_loss improved from 0.39379 to 0.32585, saving model to model.weights.best.hdf5  
860/860 [=====] - 48s 56ms/step - loss: 0.4282 - accuracy: 0.8456 - val\_loss: 0.3259 - val\_accuracy: 0.8888  
Epoch 3/10  
859/860 [=====>.] - ETA: 0s - loss: 0.3810 - accuracy: 0.8605  
Epoch 3: val\_loss improved from 0.32585 to 0.30976, saving model to model.weights.best.hdf5  
860/860 [=====] - 46s 53ms/step - loss: 0.3811 - accuracy: 0.8604 - val\_loss: 0.3098 - val\_accuracy: 0.8862  
Epoch 4/10  
859/860 [=====>.] - ETA: 0s - loss: 0.3547 - accuracy: 0.8685  
Epoch 4: val\_loss improved from 0.30976 to 0.28613, saving model to model.weights.best.hdf5  
860/860 [=====] - 47s 55ms/step - loss: 0.3548 - accuracy: 0.8685 - val\_loss: 0.2861 - val\_accuracy: 0.8944  
Epoch 5/10  
859/860 [=====>.] - ETA: 0s - loss: 0.3342 - accuracy: 0.8786  
Epoch 5: val\_loss improved from 0.28613 to 0.26990, saving model to model.weights.best.hdf5  
860/860 [=====] - 47s 54ms/step - loss: 0.3342 - accuracy: 0.8786 - val\_loss: 0.2699 - val\_accuracy: 0.8996  
Epoch 6/10  
859/860 [=====>.] - ETA: 0s - loss: 0.3149 - accuracy: 0.8833  
Epoch 6: val\_loss improved from 0.26990 to 0.26065, saving model to model.weights.best.hdf5  
860/860 [=====] - 42s 49ms/step - loss: 0.3148 - accuracy: 0.8833 - val\_loss: 0.2606 - val\_accuracy: 0.9028  
Epoch 7/10

Figure 1

Accuracy (>90%):

```
Epoch 10/10  
860/860 [=====] - ETA: 0s - loss: 0.2733 - accuracy: 0.8989  
Epoch 10: val_loss did not improve from 0.23637  
860/860 [=====] - 44s 51ms/step - loss: 0.2733 - accuracy: 0.8989 - val_loss: 0.2539 - val_accuracy: 0.9050  
  
<keras.callbacks.History at 0x167e2142d40>
```

```
1 model.load_weights('model.weights.best.hdf5')
```

[10] Python

```
1 score = model.evaluate(x_test, y_test, verbose=0)
2
3 # Print test accuracy
4 print('\n', 'Test accuracy:', score[1])
```

[11] Python

... Test accuracy: 0.9071000218391418

Figure 2

```

epoch 1/30 [=====>.] - ETA: 0s - loss: 316.4487 - mse: 316.4487
170/172 [=====] - 9s 27ms/step - loss: 315.1142 - mse: 315.1142 - val_loss: 230.9436 - val_mse: 230.9436
Epoch 1: val_loss improved from inf to 230.94365, saving model to final_model.weights.best.hdf5
epoch 2/30 [=====>.] - ETA: 0s - loss: 219.2391 - mse: 219.2391
171/172 [=====] - 4s 21ms/step - loss: 219.3547 - mse: 219.3547 - val_loss: 223.4348 - val_mse: 223.4348
Epoch 2: val_loss improved from 230.94365 to 223.43481, saving model to final_model.weights.best.hdf5
epoch 3/30 [=====>.] - ETA: 0s - loss: 213.1149 - mse: 213.1149
172/172 [=====] - 3s 20ms/step - loss: 212.8770 - mse: 212.8770 - val_loss: 224.1610 - val_mse: 224.1610
Epoch 3: val_loss did not improve from 223.43481
epoch 4/30 [=====>.] - ETA: 0s - loss: 208.9355 - mse: 208.9355
170/172 [=====] - 4s 21ms/step - loss: 209.1920 - mse: 209.1920 - val_loss: 215.1932 - val_mse: 215.1932
Epoch 4: val_loss improved from 223.43481 to 215.19318, saving model to final_model.weights.best.hdf5
epoch 5/30 [=====>.] - ETA: 0s - loss: 204.6415 - mse: 204.6415
172/172 [=====] - 4s 21ms/step - loss: 204.3024 - mse: 204.3024 - val_loss: 208.9575 - val_mse: 208.9575
Epoch 5: val_loss improved from 215.19318 to 208.95747, saving model to final_model.weights.best.hdf5
epoch 6/30 [=====>.] - ETA: 0s - loss: 199.9973 - mse: 199.9973
171/172 [=====] - 4s 23ms/step - loss: 199.7521 - mse: 199.7521 - val_loss: 206.6173 - val_mse: 206.6173
Epoch 6: val_loss improved from 208.95747 to 206.61728, saving model to final_model.weights.best.hdf5
epoch 7/30 [=====>.] - ETA: 0s - loss: 198.0234 - mse: 198.0234
172/172 [=====] - 4s 21ms/step - loss: 198.0234 - mse: 198.0234 - val_loss: 204.0154 - val_mse: 204.0154
Epoch 7: val_loss improved from 206.61728 to 204.01535, saving model to final_model.weights.best.hdf5
epoch 8/30 [=====>.] - ETA: 0s - loss: 195.7589 - mse: 195.7589
172/172 [=====] - 3s 18ms/step - loss: 196.0714 - mse: 196.0714 - val_loss: 210.3815 - val_mse: 210.3815
Epoch 8: val_loss did not improve from 204.01535
epoch 9/30 [=====>.] - ETA: 0s - loss: 195.1278 - mse: 195.1278
172/172 [=====] - 3s 18ms/step - loss: 195.1278 - mse: 195.1278 - val_loss: 222.5622 - val_mse: 222.5622
Epoch 9: val_loss did not improve from 204.01535
epoch 10/30 [=====>.] - ETA: 0s - loss: 192.4627 - mse: 192.4627
170/172 [=====] - 4s 25ms/step - loss: 192.8060 - mse: 192.8060 - val_loss: 200.3615 - val_mse: 200.3615
Epoch 10: val_loss improved from 204.01535 to 200.36147, saving model to final_model.weights.best.hdf5
epoch 11/30 [=====>.] - ETA: 0s - loss: 192.0828 - mse: 192.0828
172/172 [=====] - 4s 21ms/step - loss: 191.7423 - mse: 191.7423 - val_loss: 198.8264 - val_mse: 198.8264
Epoch 11: val_loss improved from 200.36147 to 198.82640, saving model to final_model.weights.best.hdf5
epoch 12/30 [=====>.] - ETA: 0s - loss: 188.1162 - mse: 188.1162
171/172 [=====] - 4s 21ms/step - loss: 189.2447 - mse: 189.2447 - val_loss: 197.7361 - val_mse: 197.7361
Epoch 12: val_loss improved from 198.82640 to 197.73607, saving model to final_model.weights.best.hdf5
epoch 13/30 [=====>.] - ETA: 0s - loss: 187.5096 - mse: 187.5096
172/172 [=====] - 4s 21ms/step - loss: 187.5096 - mse: 187.5096 - val_loss: 198.2378 - val_mse: 198.2378
Epoch 13: val_loss did not improve from 197.73607
epoch 14/30 [=====>.] - ETA: 0s - loss: 187.5096 - mse: 187.5096
171/172 [=====] - 3s 18ms/step - loss: 187.8819 - mse: 187.8819 - val_loss: 197.8581 - val_mse: 197.8581
Epoch 14: val_loss did not improve from 197.73607
epoch 15/30 [=====>.] - ETA: 0s - loss: 187.4577 - mse: 187.4577
172/172 [=====] - 3s 18ms/step - loss: 187.4577 - mse: 187.4577 - val_loss: 200.9349 - val_mse: 200.9349
Epoch 15: val_loss did not improve from 197.73607
epoch 16/30 [=====>.] - ETA: 0s - loss: 187.8938 - mse: 187.8938
172/172 [=====] - 4s 21ms/step - loss: 187.5965 - mse: 187.5965 - val_loss: 194.8298 - val_mse: 194.8298
Epoch 16: val_loss improved from 197.73607 to 194.82982, saving model to final_model.weights.best.hdf5
epoch 17/30 [=====>.] - ETA: 0s - loss: 184.0607 - mse: 184.0607
171/172 [=====] - 3s 20ms/step - loss: 184.0161 - mse: 184.0161 - val_loss: 194.8711 - val_mse: 194.8711
Epoch 17: val_loss did not improve from 194.82982
epoch 18/30 [=====>.] - ETA: 0s - loss: 184.2182 - mse: 184.2182
172/172 [=====] - 3s 19ms/step - loss: 184.6190 - mse: 184.6190 - val_loss: 205.0432 - val_mse: 205.0432
Epoch 18: val_loss did not improve from 194.82982
epoch 19/30 [=====>.] - ETA: 0s - loss: 185.7414 - mse: 185.7414
172/172 [=====] - 4s 21ms/step - loss: 185.7414 - mse: 185.7414 - val_loss: 193.2155 - val_mse: 193.2155
Epoch 19: val_loss improved from 194.82982 to 193.21545, saving model to final_model.weights.best.hdf5
epoch 20/30 [=====>.] - ETA: 0s - loss: 183.3222 - mse: 183.3222
170/172 [=====] - 3s 19ms/step - loss: 183.6099 - mse: 183.6099 - val_loss: 194.8198 - val_mse: 194.8198
Epoch 20: val_loss did not improve from 193.21545
epoch 21/30 [=====>.] - ETA: 0s - loss: 183.7622 - mse: 183.7622
171/172 [=====] - 3s 19ms/step - loss: 183.8198 - mse: 183.8198 - val_loss: 202.3373 - val_mse: 202.3373
Epoch 21: val_loss did not improve from 193.21545
epoch 22/30 [=====>.] - ETA: 0s - loss: 182.7721 - mse: 182.7721
172/172 [=====] - 3s 18ms/step - loss: 183.0577 - mse: 183.0577 - val_loss: 194.4586 - val_mse: 194.4586
Epoch 22: val_loss did not improve from 193.21545
epoch 23/30 [=====>.] - ETA: 0s - loss: 179.8648 - mse: 179.8648
171/172 [=====] - 3s 18ms/step - loss: 179.8958 - mse: 179.8958 - val_loss: 220.3992 - val_mse: 220.3992
Epoch 23: val_loss did not improve from 193.21545
epoch 24/30 [=====>.] - ETA: 0s - loss: 182.1721 - mse: 182.1721
172/172 [=====] - 3s 20ms/step - loss: 182.1721 - mse: 182.1721 - val_loss: 193.6981 - val_mse: 193.6981
Epoch 24: val_loss did not improve from 193.21545
epoch 25/30 [=====>.] - ETA: 0s - loss: 180.3846 - mse: 180.3846
172/172 [=====] - 3s 20ms/step - loss: 180.3846 - mse: 180.3846 - val_loss: 193.21545
Epoch 25: val_loss did not improve from 193.21545

```

Figure 3

```

epoch 13: val_loss did not improve from 197.73607
172/172 [=====] - 4s 21ms/step - loss: 190.8125 - mse: 190.8125 - val_loss: 198.2378 - val_mse: 198.2378
Epoch 14/30 [=====>.] - ETA: 0s - loss: 187.5096 - mse: 187.5096
171/172 [=====] - 3s 18ms/step - loss: 187.8819 - mse: 187.8819 - val_loss: 197.8581 - val_mse: 197.8581
Epoch 14: val_loss did not improve from 197.73607
epoch 15/30 [=====>.] - ETA: 0s - loss: 187.4577 - mse: 187.4577
172/172 [=====] - 3s 18ms/step - loss: 187.4577 - mse: 187.4577 - val_loss: 200.9349 - val_mse: 200.9349
Epoch 15: val_loss did not improve from 197.73607
epoch 16/30 [=====>.] - ETA: 0s - loss: 187.8938 - mse: 187.8938
172/172 [=====] - 4s 21ms/step - loss: 187.5965 - mse: 187.5965 - val_loss: 194.8298 - val_mse: 194.8298
Epoch 16: val_loss improved from 197.73607 to 194.82982, saving model to final_model.weights.best.hdf5
epoch 17/30 [=====>.] - ETA: 0s - loss: 184.0607 - mse: 184.0607
171/172 [=====] - 3s 20ms/step - loss: 184.0161 - mse: 184.0161 - val_loss: 194.8711 - val_mse: 194.8711
Epoch 17: val_loss did not improve from 194.82982
epoch 18/30 [=====>.] - ETA: 0s - loss: 184.2182 - mse: 184.2182
172/172 [=====] - 3s 19ms/step - loss: 184.6190 - mse: 184.6190 - val_loss: 205.0432 - val_mse: 205.0432
Epoch 18: val_loss did not improve from 194.82982
epoch 19/30 [=====>.] - ETA: 0s - loss: 185.7414 - mse: 185.7414
172/172 [=====] - 4s 21ms/step - loss: 185.7414 - mse: 185.7414 - val_loss: 193.2155 - val_mse: 193.2155
Epoch 19: val_loss improved from 194.82982 to 193.21545, saving model to final_model.weights.best.hdf5
epoch 20/30 [=====>.] - ETA: 0s - loss: 183.3222 - mse: 183.3222
170/172 [=====] - 3s 19ms/step - loss: 183.6099 - mse: 183.6099 - val_loss: 194.8198 - val_mse: 194.8198
Epoch 20: val_loss did not improve from 193.21545
epoch 21/30 [=====>.] - ETA: 0s - loss: 183.7622 - mse: 183.7622
171/172 [=====] - 3s 19ms/step - loss: 183.8198 - mse: 183.8198 - val_loss: 202.3373 - val_mse: 202.3373
Epoch 21: val_loss did not improve from 193.21545
epoch 22/30 [=====>.] - ETA: 0s - loss: 182.7721 - mse: 182.7721
172/172 [=====] - 3s 18ms/step - loss: 183.0577 - mse: 183.0577 - val_loss: 194.4586 - val_mse: 194.4586
Epoch 22: val_loss did not improve from 193.21545
epoch 23/30 [=====>.] - ETA: 0s - loss: 179.8648 - mse: 179.8648
171/172 [=====] - 3s 18ms/step - loss: 179.8958 - mse: 179.8958 - val_loss: 220.3992 - val_mse: 220.3992
Epoch 23: val_loss did not improve from 193.21545
epoch 24/30 [=====>.] - ETA: 0s - loss: 182.1721 - mse: 182.1721
172/172 [=====] - 3s 20ms/step - loss: 182.1721 - mse: 182.1721 - val_loss: 193.6981 - val_mse: 193.6981
Epoch 24: val_loss did not improve from 193.21545
epoch 25/30 [=====>.] - ETA: 0s - loss: 180.3846 - mse: 180.3846
172/172 [=====] - 3s 20ms/step - loss: 180.3846 - mse: 180.3846 - val_loss: 193.21545
Epoch 25: val_loss did not improve from 193.21545

```

Figure 4

```

172/172 [=====] - ETA: 0s - loss: 185.7414 - mse: 185.7414
Epoch 19: val_loss improved from 194.82982 to 193.21545, saving model to final_model.weights.best.hdf5
172/172 [=====] - 4s 21ms/step - loss: 185.7414 - mse: 185.7414 - val_loss: 193.2155 - val_mse: 193.2155
Epoch 20/30
170/172 [=====>.] - ETA: 0s - loss: 183.3222 - mse: 183.3222
Epoch 20: val_loss did not improve from 193.21545
172/172 [=====] - 3s 19ms/step - loss: 183.6099 - mse: 183.6099 - val_loss: 194.8198 - val_mse: 194.8198
Epoch 21/30
171/172 [=====>.] - ETA: 0s - loss: 183.7622 - mse: 183.7622
Epoch 21: val_loss did not improve from 193.21545
172/172 [=====] - 3s 19ms/step - loss: 183.8198 - mse: 183.8198 - val_loss: 202.3373 - val_mse: 202.3373
Epoch 22/30
170/172 [=====>.] - ETA: 0s - loss: 182.7721 - mse: 182.7721
Epoch 22: val_loss did not improve from 193.21545
172/172 [=====] - 3s 18ms/step - loss: 183.0577 - mse: 183.0577 - val_loss: 194.4586 - val_mse: 194.4586
Epoch 23/30
171/172 [=====>.] - ETA: 0s - loss: 179.8648 - mse: 179.8648
Epoch 23: val_loss did not improve from 193.21545
172/172 [=====] - 3s 18ms/step - loss: 179.8958 - mse: 179.8958 - val_loss: 220.3992 - val_mse: 220.3992
Epoch 24/30
172/172 [=====] - ETA: 0s - loss: 182.1721 - mse: 182.1721
Epoch 24: val_loss did not improve from 193.21545
172/172 [=====] - 3s 20ms/step - loss: 182.1721 - mse: 182.1721 - val_loss: 193.6981 - val_mse: 193.6981
Epoch 25/30
172/172 [=====] - ETA: 0s - loss: 180.3846 - mse: 180.3846
Epoch 25: val_loss did not improve from 193.21545
172/172 [=====] - 3s 18ms/step - loss: 180.3846 - mse: 180.3846 - val_loss: 194.0184 - val_mse: 194.0184
Epoch 26/30
170/172 [=====>.] - ETA: 0s - loss: 178.0973 - mse: 178.0973
Epoch 26: val_loss improved from 193.21545 to 191.14980, saving model to final_model.weights.best.hdf5
172/172 [=====] - 4s 22ms/step - loss: 179.1857 - mse: 179.1857 - val_loss: 191.1498 - val_mse: 191.1498
Epoch 27/30
171/172 [=====>.] - ETA: 0s - loss: 179.4552 - mse: 179.4552
Epoch 27: val_loss did not improve from 191.14980
172/172 [=====] - 3s 18ms/step - loss: 179.5190 - mse: 179.5190 - val_loss: 191.9236 - val_mse: 191.9236
Epoch 28/30
169/172 [=====>.] - ETA: 0s - loss: 178.4414 - mse: 178.4414
Epoch 28: val_loss did not improve from 191.14980
172/172 [=====] - 4s 21ms/step - loss: 177.7691 - mse: 177.7691 - val_loss: 194.5526 - val_mse: 194.5526
Epoch 29/30
172/172 [=====] - ETA: 0s - loss: 180.9464 - mse: 180.9464
Epoch 29: val_loss improved from 191.14980 to 190.81418, saving model to final_model.weights.best.hdf5
172/172 [=====] - 4s 21ms/step - loss: 180.9464 - mse: 180.9464 - val_loss: 190.8142 - val_mse: 190.8142
Epoch 30/30
172/172 [=====] - ETA: 0s - loss: 177.7907 - mse: 177.7907
Epoch 30: val_loss did not improve from 190.81418
172/172 [=====] - 3s 18ms/step - loss: 177.7907 - mse: 177.7907 - val_loss: 193.7686 - val_mse: 193.7686
47/47 [=====] - 1s 20ms/step - loss: 164.2970 - mse: 164.2970
Test RMSE = 12.817837231527998

```

Figure 5

From the above screenshots, the testing RMSE can be seen to be 12.81 (Figure 5, last line)

Training MSE is 177.79, corresponding to RMSE of 13.33

Validation MSE is 193.76 corresponding to an RMSE of 13.92