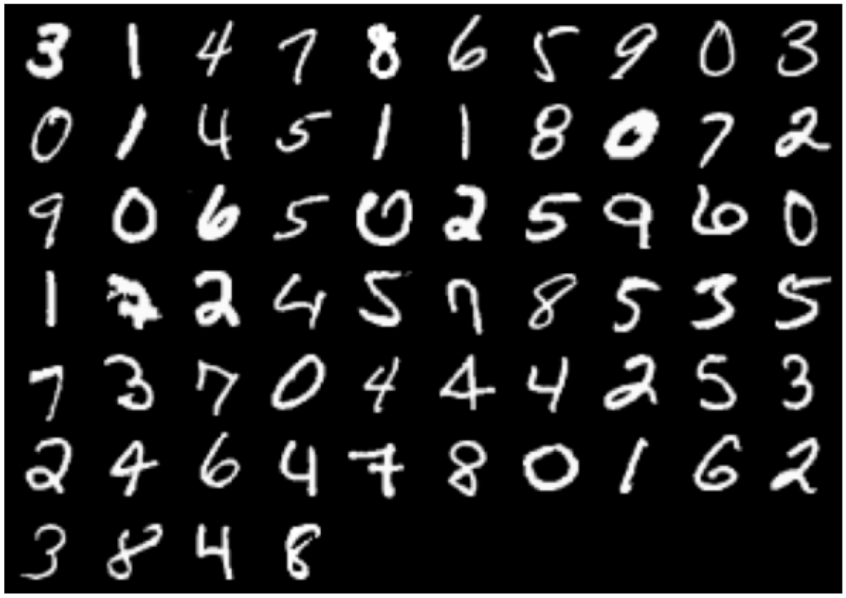
TASK
Title: Report on Implementing a VAE using CNN and Pytorch

The following are the main results and key findings:

Analysis (in different experiments):
Optimizer selection: I use Adam as an optimizer in this task because of its advantages over other optimization methods. It combines the advantages of AdaGrad and RMSPop by using both momentum and learning rate. It is widely used for various models and datasets and highly effective.



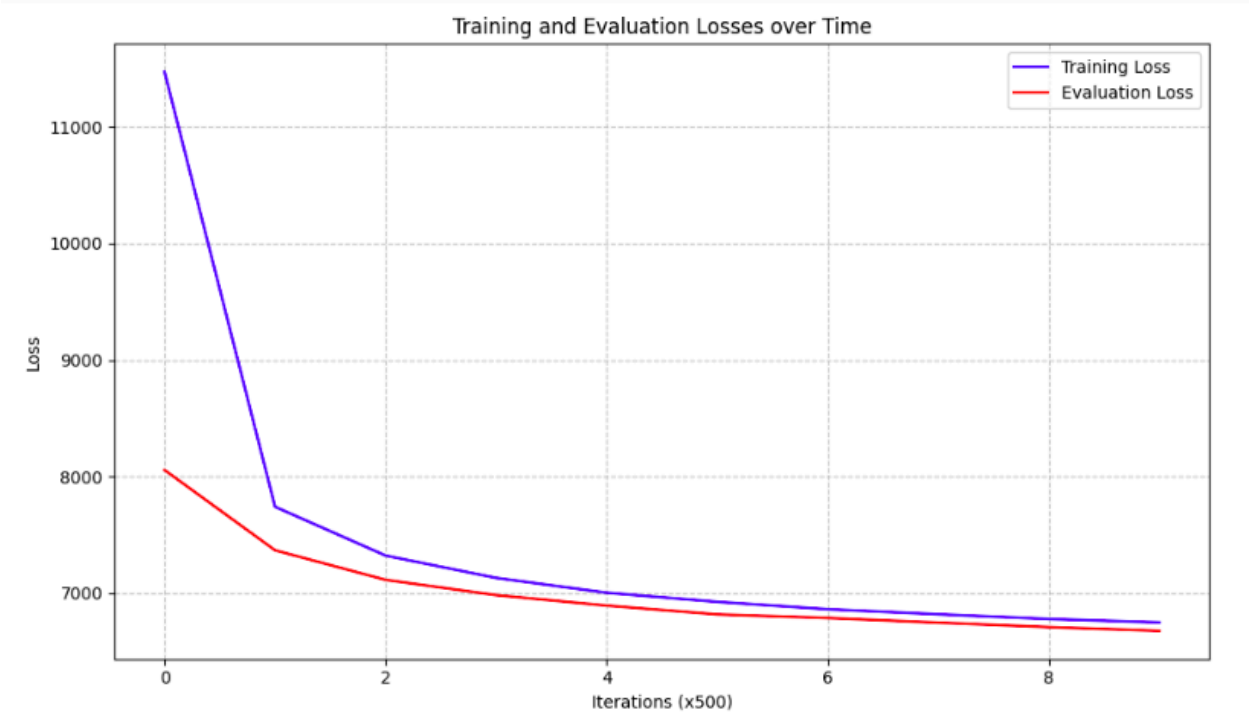
Experiment: 01
Hyperparameters:

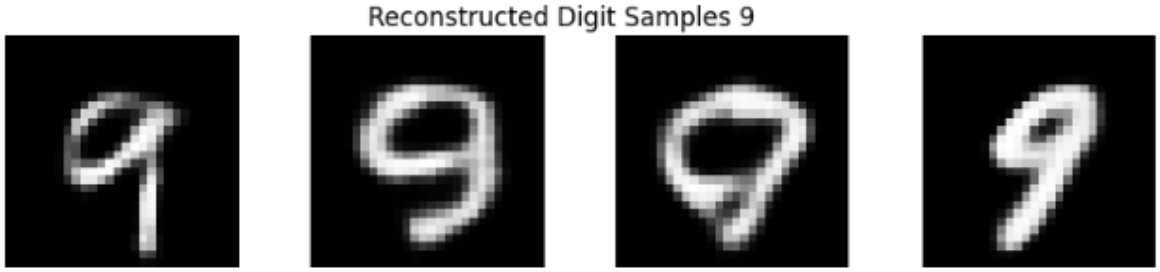
- Learning rate = 3e-4
- Batch size: 64
- Number of epochs: 10
- Optimizer: Adam
- latent_dims=2

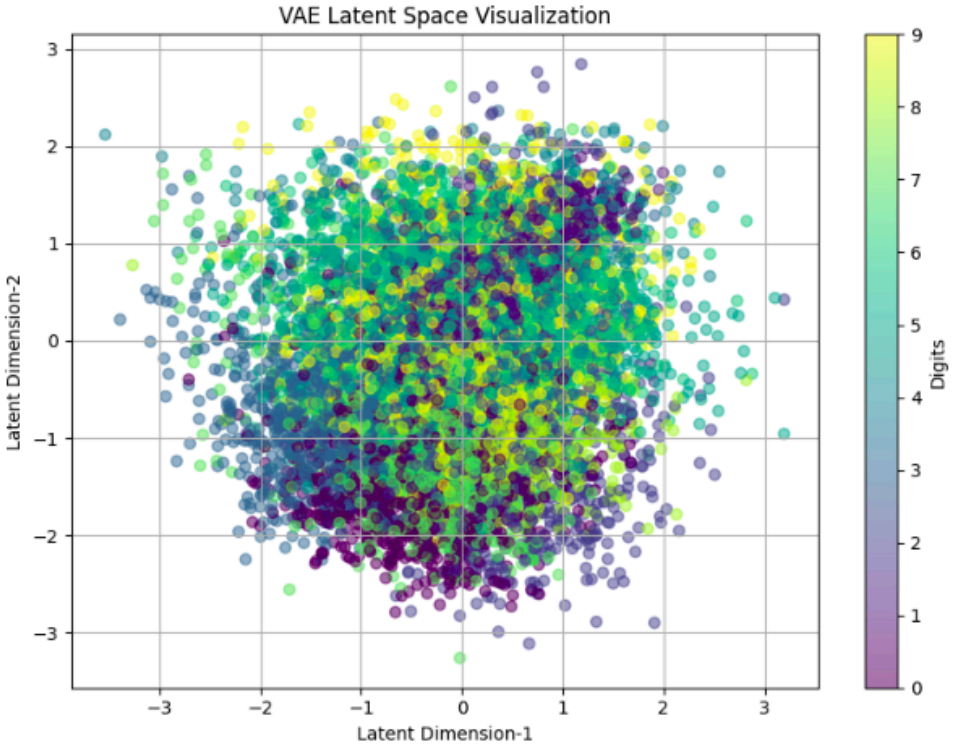
Results: Training loss Real is 6747.5687, Validation loss is `6674.9966`.

```
Epoch [1/10], Loss: 3865.9668: 100%|██████████| 938/938 [01:04<00:00, 14.52it/s]
Epoch [1/10], Training Loss: 11471.2268
Epoch [1/10], Validation Loss: 8055.3444
Epoch [2/10], Loss: 3693.2900: 100%|██████████| 938/938 [01:04<00:00, 14.63it/s]
Epoch [2/10], Training Loss: 7739.6027
Epoch [2/10], Validation Loss: 7366.5055
Epoch [3/10], Loss: 3637.0996: 100%|██████████| 938/938 [01:12<00:00, 13.00it/s]
Epoch [3/10], Training Loss: 7320.9809
Epoch [3/10], Validation Loss: 7112.7607
Epoch [4/10], Loss: 3519.9058: 100%|██████████| 938/938 [01:11<00:00, 13.18it/s]
Epoch [4/10], Training Loss: 7129.3436
Epoch [4/10], Validation Loss: 6981.7134
Epoch [5/10], Loss: 3533.1001: 100%|██████████| 938/938 [01:00<00:00, 15.38it/s]
Epoch [5/10], Training Loss: 7002.1939
Epoch [5/10], Validation Loss: 6891.9624
Epoch [6/10], Loss: 3391.9656: 100%|██████████| 938/938 [01:07<00:00, 13.88it/s]
Epoch [6/10], Training Loss: 6924.0980
Epoch [6/10], Validation Loss: 6816.3133
Epoch [7/10], Loss: 3544.5020: 100%|██████████| 938/938 [01:02<00:00, 15.10it/s]
Epoch [7/10], Training Loss: 6860.6265
Epoch [7/10], Validation Loss: 6785.5697
Epoch [8/10], Loss: 3523.6157: 100%|██████████| 938/938 [01:11<00:00, 13.13it/s]
Epoch [8/10], Training Loss: 6817.3507
Epoch [8/10], Validation Loss: 6745.6117
Epoch [9/10], Loss: 3485.3535: 100%|██████████| 938/938 [01:02<00:00, 15.00it/s]
Epoch [9/10], Training Loss: 6776.9879
Epoch [9/10], Validation Loss: 6707.2932
Epoch [10/10], Loss: 3373.1541: 100%|██████████| 938/938 [01:05<00:00, 14.36it/s]
Epoch [10/10], Training Loss: 6747.5687
Epoch [10/10], Validation Loss: 6674.9966
```

Loss Curve:







Experiment: 02

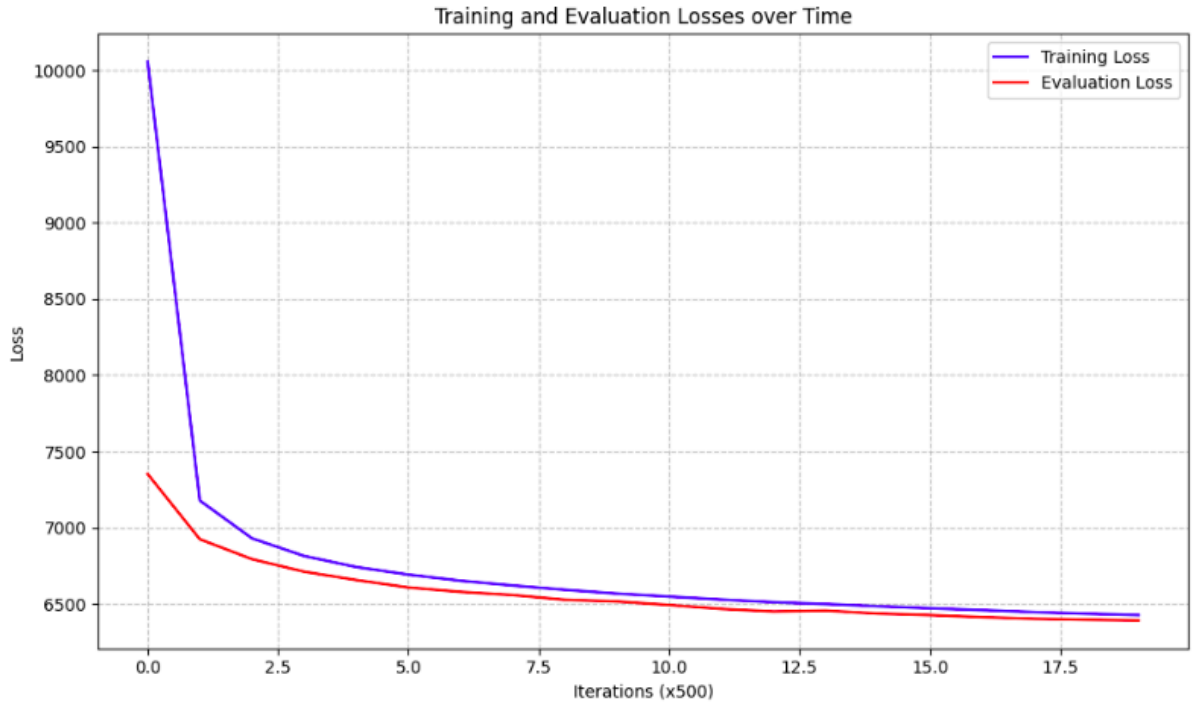
Hyperparameters:

- Learning rate = 1e-3
- Batch size: 64
- Number of epochs: 20
- Optimizer: Adam
- latent_dims=2

Results: Training loss Real is 6426.5574, Validation loss is 6391.1942.

```
Epoch [11/20], Loss: 3050.0029: 100%|██████████| 938/938 [01:02<00:00, 14.98it/s]
Epoch [11/20], Training Loss: 6547.8135
Epoch [11/20], Validation Loss: 6492.6531
Epoch [12/20], Loss: 3518.5151: 100%|██████████| 938/938 [01:02<00:00, 15.00it/s]
Epoch [12/20], Training Loss: 6528.2725
Epoch [12/20], Validation Loss: 6466.8774
Epoch [13/20], Loss: 3373.2927: 100%|██████████| 938/938 [01:02<00:00, 14.94it/s]
Epoch [13/20], Training Loss: 6510.8491
Epoch [13/20], Validation Loss: 6450.0051
Epoch [14/20], Loss: 3427.8181: 100%|██████████| 938/938 [01:02<00:00, 15.07it/s]
Epoch [14/20], Training Loss: 6498.7841
Epoch [14/20], Validation Loss: 6455.4288
Epoch [15/20], Loss: 3416.6707: 100%|██████████| 938/938 [01:01<00:00, 15.28it/s]
Epoch [15/20], Training Loss: 6484.5820
Epoch [15/20], Validation Loss: 6436.3190
Epoch [16/20], Loss: 3550.5537: 100%|██████████| 938/938 [01:02<00:00, 15.00it/s]
Epoch [16/20], Training Loss: 6471.0754
Epoch [16/20], Validation Loss: 6426.2300
Epoch [17/20], Loss: 3455.4819: 100%|██████████| 938/938 [01:02<00:00, 14.99it/s]
Epoch [17/20], Training Loss: 6459.1066
Epoch [17/20], Validation Loss: 6412.8294
Epoch [18/20], Loss: 3419.6609: 100%|██████████| 938/938 [01:05<00:00, 14.34it/s]
Epoch [18/20], Training Loss: 6445.8301
Epoch [18/20], Validation Loss: 6402.1805
Epoch [19/20], Loss: 3178.1301: 100%|██████████| 938/938 [01:02<00:00, 14.99it/s]
Epoch [19/20], Training Loss: 6435.4437
Epoch [19/20], Validation Loss: 6395.9531
Epoch [20/20], Loss: 3235.5132: 100%|██████████| 938/938 [01:02<00:00, 15.00it/s]
Epoch [20/20], Training Loss: 6426.5574
Epoch [20/20], Validation Loss: 6391.1942
```

Loss Curve:



Experiment: 03

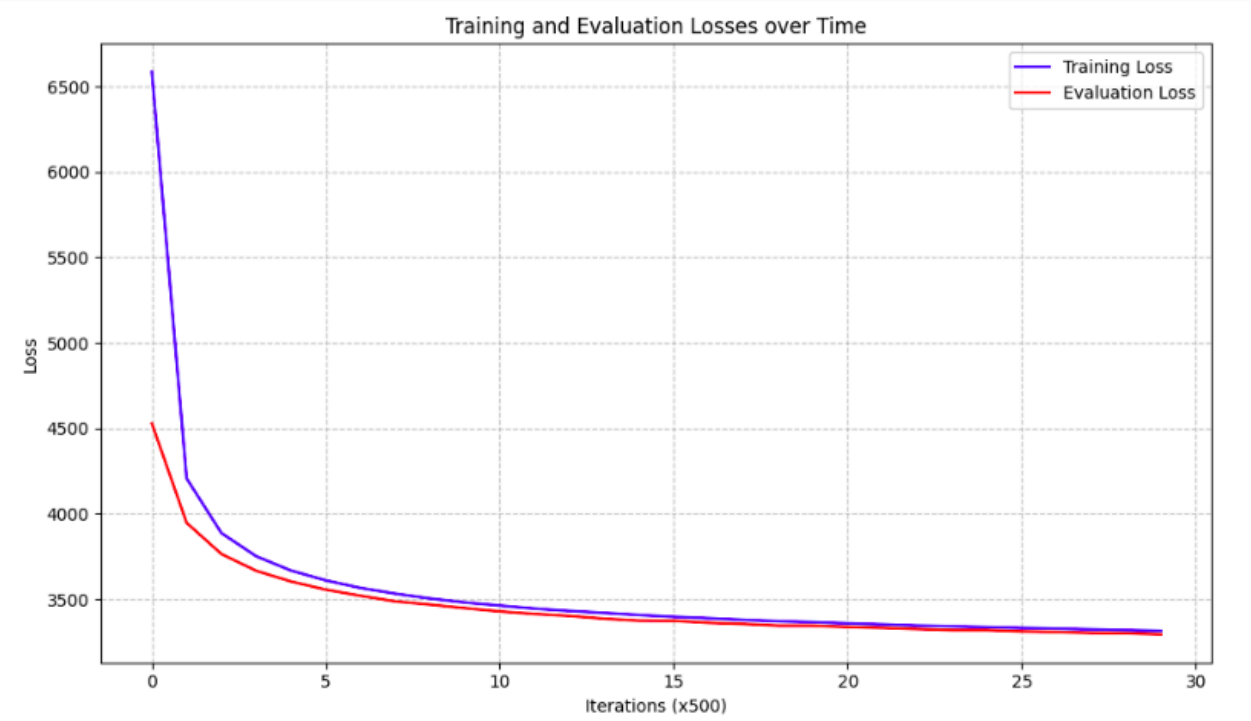
Hyperparameters:

- Learning rate = 1e-4
- Batch size: 32
- Number of epochs: 30
- Optimizer: Adam
- latent_dims=2

Results: Training loss Real is 3314.1463, Validation loss is `3293.8164`.

```
Epoch [20/30], Validation Loss: 3345.1147
Epoch [21/30], Loss: 3309.0574: 100%|██████████| 1875/1875 [01:13<00:00, 25.51it/s]
Epoch [21/30], Training Loss: 3358.2247
Epoch [21/30], Validation Loss: 3336.9521
Epoch [22/30], Loss: 3469.5303: 100%|██████████| 1875/1875 [01:13<00:00, 25.46it/s]
Epoch [22/30], Training Loss: 3352.0533
Epoch [22/30], Validation Loss: 3331.8638
Epoch [23/30], Loss: 3273.2024: 100%|██████████| 1875/1875 [01:14<00:00, 25.33it/s]
Epoch [23/30], Training Loss: 3345.2382
Epoch [23/30], Validation Loss: 3325.0315
Epoch [24/30], Loss: 3215.5449: 100%|██████████| 1875/1875 [01:14<00:00, 25.21it/s]
Epoch [24/30], Training Loss: 3341.4839
Epoch [24/30], Validation Loss: 3318.6527
Epoch [25/30], Loss: 3482.9419: 100%|██████████| 1875/1875 [01:14<00:00, 25.05it/s]
Epoch [25/30], Training Loss: 3336.0294
Epoch [25/30], Validation Loss: 3318.4912
Epoch [26/30], Loss: 3369.7915: 100%|██████████| 1875/1875 [01:14<00:00, 25.13it/s]
Epoch [26/30], Training Loss: 3331.4704
Epoch [26/30], Validation Loss: 3311.1080
Epoch [27/30], Loss: 3360.7231: 100%|██████████| 1875/1875 [01:14<00:00, 25.29it/s]
Epoch [27/30], Training Loss: 3327.4538
Epoch [27/30], Validation Loss: 3307.8651
Epoch [28/30], Loss: 3372.9275: 100%|██████████| 1875/1875 [01:14<00:00, 25.32it/s]
Epoch [28/30], Training Loss: 3323.0256
Epoch [28/30], Validation Loss: 3301.9937
Epoch [29/30], Loss: 3469.5254: 100%|██████████| 1875/1875 [01:13<00:00, 25.58it/s]
Epoch [29/30], Training Loss: 3318.5529
Epoch [29/30], Validation Loss: 3300.3791
Epoch [30/30], Loss: 3173.9385: 100%|██████████| 1875/1875 [01:13<00:00, 25.60it/s]
Epoch [30/30], Training Loss: 3314.1463
Epoch [30/30], Validation Loss: 3293.8164
```

Loss Curve:



Experiment: 04

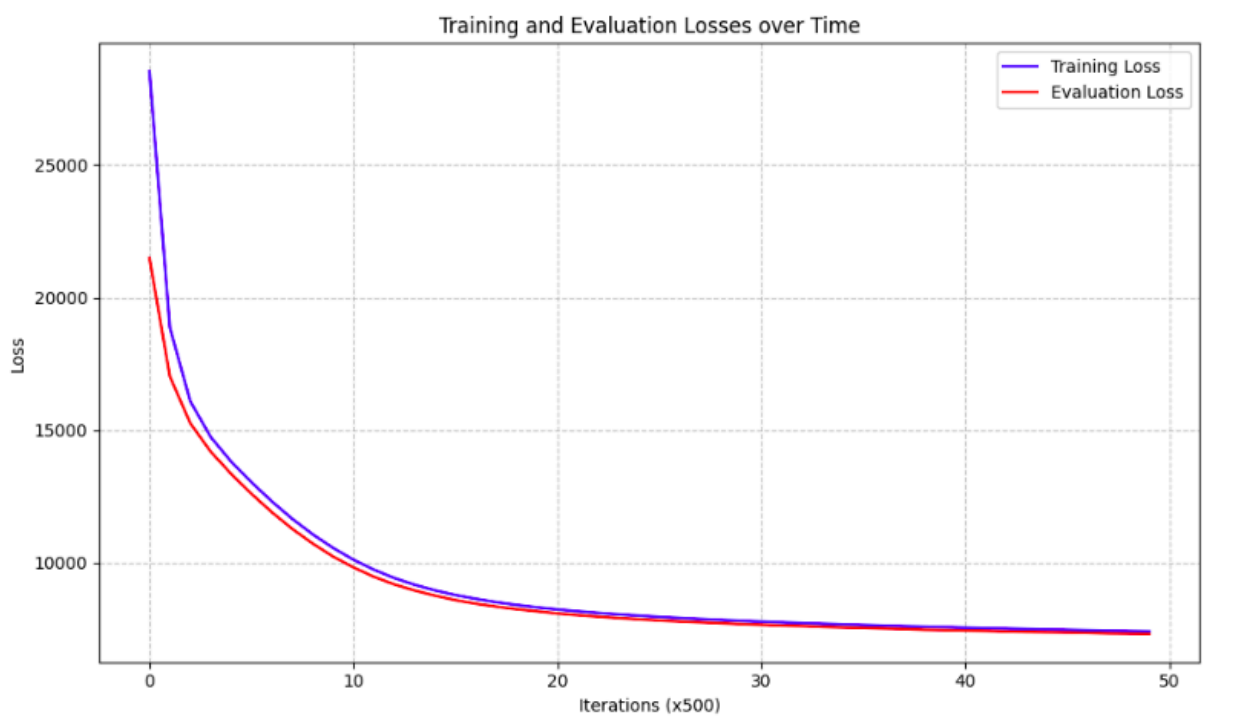
Hyperparameters:

- Learning rate = 1e-5
- Batch size: 64
- Number of epochs: 50
- Optimizer: Adam
- latent_dims=2

Results: Training loss Real is 7414.9272, Validation loss is 7320.2384.

```
Epoch [40/50], Validation Loss: 7462.0411
Epoch [41/50], Loss: 3429.2131: 100%|██████████| 938/938 [00:59<00:00, 15.81it/s]
Epoch [41/50], Training Loss: 7553.0778
Epoch [41/50], Validation Loss: 7447.1588
Epoch [42/50], Loss: 3731.1851: 100%|██████████| 938/938 [01:00<00:00, 15.54it/s]
Epoch [42/50], Training Loss: 7535.4207
Epoch [42/50], Validation Loss: 7432.7916
Epoch [43/50], Loss: 3918.0881: 100%|██████████| 938/938 [01:00<00:00, 15.58it/s]
Epoch [43/50], Training Loss: 7520.4544
Epoch [43/50], Validation Loss: 7410.1770
Epoch [44/50], Loss: 3761.5823: 100%|██████████| 938/938 [01:00<00:00, 15.51it/s]
Epoch [44/50], Training Loss: 7501.6737
Epoch [44/50], Validation Loss: 7395.7867
Epoch [45/50], Loss: 3597.0891: 100%|██████████| 938/938 [01:00<00:00, 15.58it/s]
Epoch [45/50], Training Loss: 7487.0029
Epoch [45/50], Validation Loss: 7381.9841
Epoch [46/50], Loss: 3344.9536: 100%|██████████| 938/938 [00:59<00:00, 15.82it/s]
Epoch [46/50], Training Loss: 7471.0665
Epoch [46/50], Validation Loss: 7372.2512
Epoch [47/50], Loss: 3809.6797: 100%|██████████| 938/938 [00:58<00:00, 15.93it/s]
Epoch [47/50], Training Loss: 7455.4930
Epoch [47/50], Validation Loss: 7357.0604
Epoch [48/50], Loss: 3560.2847: 100%|██████████| 938/938 [00:59<00:00, 15.84it/s]
Epoch [48/50], Training Loss: 7442.9050
Epoch [48/50], Validation Loss: 7336.5918
Epoch [49/50], Loss: 3719.4346: 100%|██████████| 938/938 [00:59<00:00, 15.65it/s]
Epoch [49/50], Training Loss: 7425.9634
Epoch [49/50], Validation Loss: 7328.0505
Epoch [50/50], Loss: 3834.2227: 100%|██████████| 938/938 [01:00<00:00, 15.57it/s]
Epoch [50/50], Training Loss: 7414.9272
Epoch [50/50], Validation Loss: 7320.2384
```

Loss Curve:



Experiment: 05

Hyperparameters:

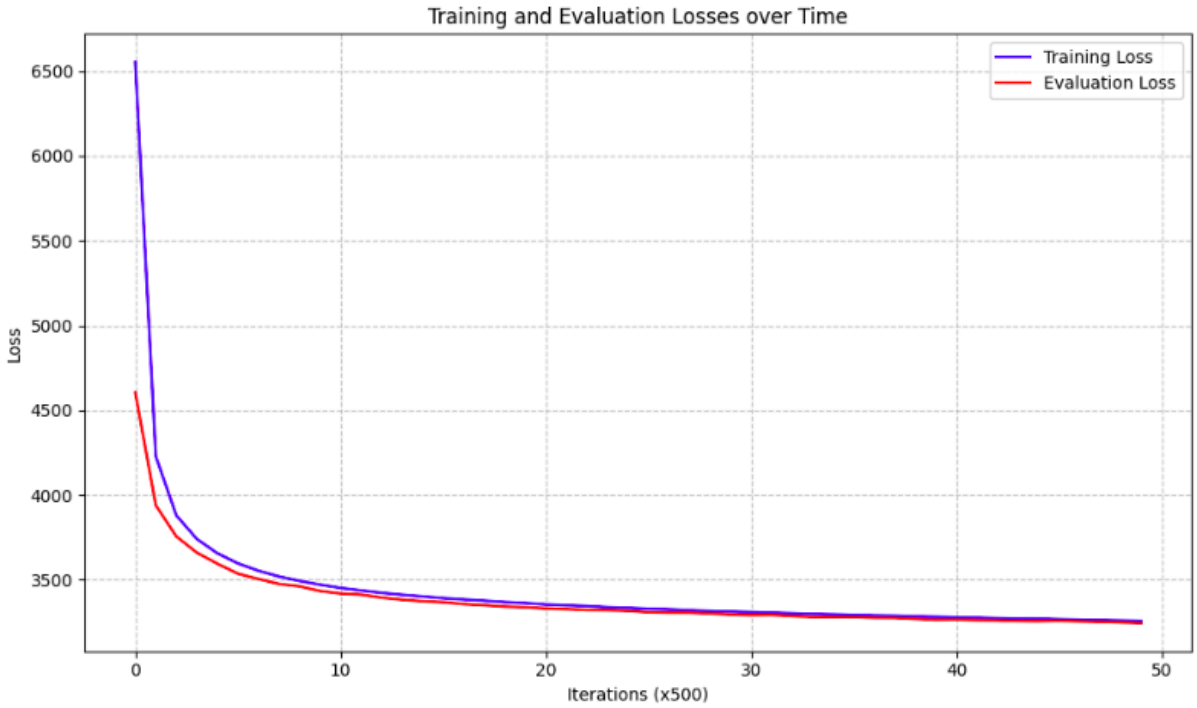
- Learning rate =1e-4
- Batch size: 32

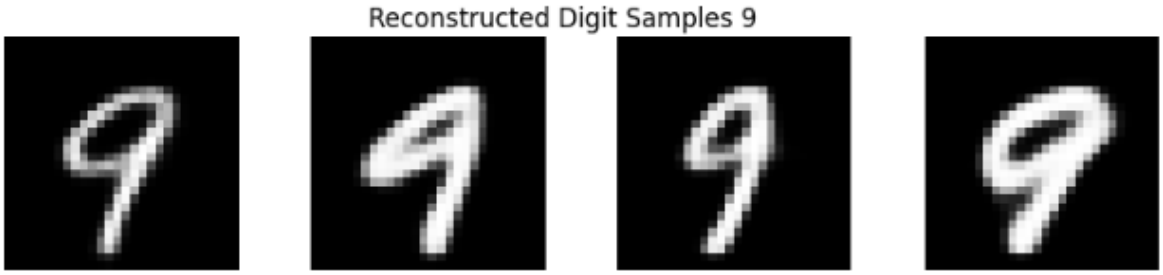
- Number of epochs: 50
- Optimizer: Adam
- latent_dims=2

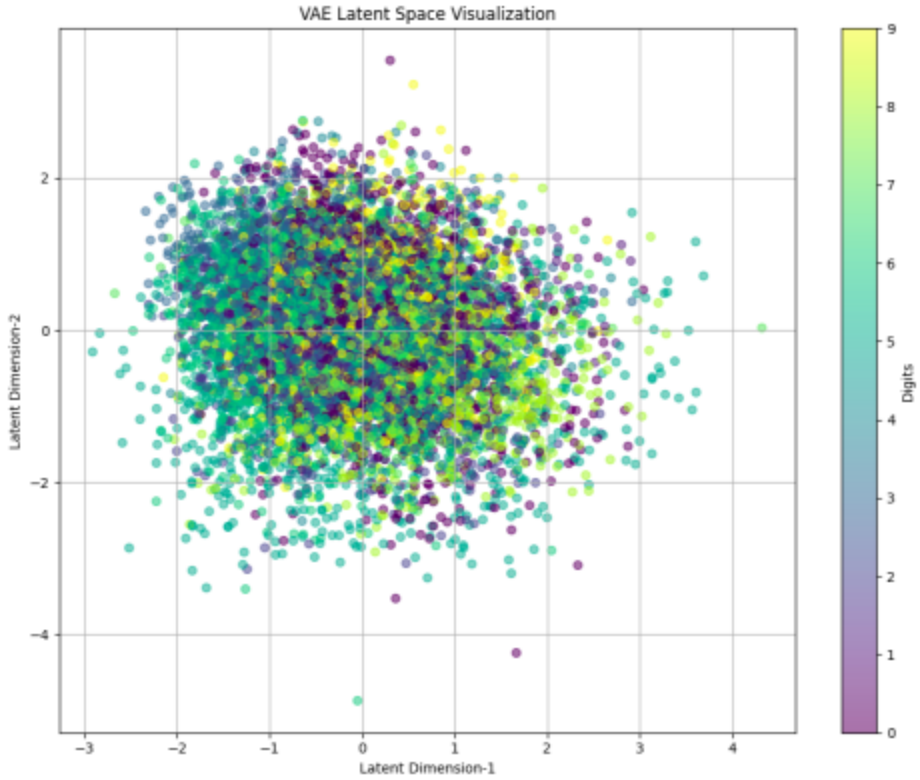
Results: Training loss Real is 6747.5687, Validation loss is `6674.9966`.

```
Epoch [39/50], Validation Loss: 3270.0987
Epoch [40/50], Loss: 3199.5906: 100%|██████████| 1875/1875 [01:11<00:00, 26.22it/s]
Epoch [40/50], Training Loss: 3282.0937
Epoch [40/50], Validation Loss: 3264.0424
Epoch [41/50], Loss: 3289.6736: 100%|██████████| 1875/1875 [01:10<00:00, 26.49it/s]
Epoch [41/50], Training Loss: 3279.0404
Epoch [41/50], Validation Loss: 3265.4452
Epoch [42/50], Loss: 3368.0020: 100%|██████████| 1875/1875 [01:11<00:00, 26.40it/s]
Epoch [42/50], Training Loss: 3276.8284
Epoch [42/50], Validation Loss: 3261.8281
Epoch [43/50], Loss: 3352.8420: 100%|██████████| 1875/1875 [01:12<00:00, 25.97it/s]
Epoch [43/50], Training Loss: 3273.3053
Epoch [43/50], Validation Loss: 3260.9109
Epoch [44/50], Loss: 3404.7515: 100%|██████████| 1875/1875 [01:11<00:00, 26.31it/s]
Epoch [44/50], Training Loss: 3271.1897
Epoch [44/50], Validation Loss: 3257.4875
Epoch [45/50], Loss: 3325.9202: 100%|██████████| 1875/1875 [01:11<00:00, 26.35it/s]
Epoch [45/50], Training Loss: 3270.5329
Epoch [45/50], Validation Loss: 3256.1386
Epoch [46/50], Loss: 3310.7358: 100%|██████████| 1875/1875 [01:12<00:00, 25.97it/s]
Epoch [46/50], Training Loss: 3267.3961
Epoch [46/50], Validation Loss: 3258.7755
Epoch [47/50], Loss: 3128.6208: 100%|██████████| 1875/1875 [01:11<00:00, 26.30it/s]
Epoch [47/50], Training Loss: 3265.0998
Epoch [47/50], Validation Loss: 3255.0698
Epoch [48/50], Loss: 3386.4614: 100%|██████████| 1875/1875 [01:11<00:00, 26.09it/s]
Epoch [48/50], Training Loss: 3262.4041
Epoch [48/50], Validation Loss: 3252.6421
Epoch [49/50], Loss: 3307.4441: 100%|██████████| 1875/1875 [01:11<00:00, 26.23it/s]
Epoch [49/50], Training Loss: 3260.2339
Epoch [49/50], Validation Loss: 3249.0833
Epoch [50/50], Loss: 3166.9255: 100%|██████████| 1875/1875 [01:11<00:00, 26.08it/s]
Epoch [50/50], Training Loss: 3257.8188
Epoch [50/50], Validation Loss: 3244.8309
```

Loss Curve:


Training and Evaluation Losses over Time
Training Loss
Evaluation Loss
Loss
6500
6000
5500
5000
4500
4000
3500
0
10
20
30
40
50
Iterations (x500)


Reconstructed Digit Samples 9


VAE Latent Space Visualization
Latent Dimension-2
Latent Dimension-1
Digits
2
0
−2
−4
−3
−2
−1
0
1
2
3
4
9
8
7
6
5
4
3
2
1
0