In [3]:

```
import numpy as np
import matplotlib.pyplot as plt
import torch
import torchvision
import torchvision.datasets as datasets
import torchvision.transforms as transforms
from torch import nn
import math
```

In [4]:

```
transform = transforms.ToTensor()
trainset = datasets.MNIST('', download=True, train=True, transform=transform)
testset = datasets.MNIST('',download=True, train=False, transform=transform)
trainset,valset=torch.utils.data.random_split(trainset,(50000,10000))
trainloader = torch.utils.data.DataLoader(trainset,batch_size=500)
valloader = torch.utils.data.DataLoader(valset,batch_size=500)
testloader = torch.utils.data.DataLoader(testset,batch_size=500)
```

```
Downloading http://yann.lecun.com/exdb/mnist/train-images-idx3-ubyt
e.gz
Downloading http://yann.lecun.com/exdb/mnist/train-images-idx3-ubyt
e.gz to MNIST/raw/train-images-idx3-ubyte.gz


Extracting MNIST/raw/train-images-idx3-ubyte.gz to MNIST/raw

Downloading http://yann.lecun.com/exdb/mnist/train-labels-idx1-ubyt
e.gz
Downloading http://yann.lecun.com/exdb/mnist/train-labels-idx1-ubyt
e.gz to MNIST/raw/train-labels-idx1-ubyte.gz


Extracting MNIST/raw/train-labels-idx1-ubyte.gz to MNIST/raw

Downloading http://yann.lecun.com/exdb/mnist/t10k-images-idx3-ubyte.
gz
Downloading http://yann.lecun.com/exdb/mnist/t10k-images-idx3-ubyte.
gz to MNIST/raw/t10k-images-idx3-ubyte.gz


Extracting MNIST/raw/t10k-images-idx3-ubyte.gz to MNIST/raw

Downloading http://yann.lecun.com/exdb/mnist/t10k-labels-idx1-ubyte.
gz
Downloading http://yann.lecun.com/exdb/mnist/t10k-labels-idx1-ubyte.
gz to MNIST/raw/t10k-labels-idx1-ubyte.gz


Extracting MNIST/raw/t10k-labels-idx1-ubyte.gz to MNIST/raw
```

QUESTION 1

In [4]:

```
#Setting Hyperparameters
learning_rate = 0.001
epochs = 5
criterion1 = nn.CrossEntropyLoss()
```

Vanilla RNN

In [33]:

```
class RNN(nn.Module):
  def __init__(self):
    super(RNN, self).__init__()
    self.rnn = nn.RNN(28,128)
    self.layer2 = nn.Linear(128, 10)

  def forward(self, X):
    X = X.permute(1, 0, 2)
    hiddenlayer=torch.zeros(1,X.size(1),128)
    _,hiddenlayer = self.rnn(X,hiddenlayer)
    out = self.layer2(hiddenlayer)
    return out.reshape(500,10)
```

In [34]:

```
#vanilla RNN model (without Regularisation)
train_loss = []
val_loss = []
val_acc = []

model1=RNN()
optimizer1 = torch.optim.Adam(model1.parameters(), lr=learning_rate)

for epoch in range(epochs):
  for i, (images, labels) in enumerate(trainloader):
    images = images.reshape(-1, 28, 28)
    outputs = model1(images)
    loss = criterion1(outputs, labels)
    train_loss.append(loss.item())

    optimizer1.zero_grad()
    loss.backward()
    optimizer1.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for images, labels in valloader:
    images = images.reshape(-1, 28, 28)
    outputs = model1(images)
    loss = criterion1(outputs, labels)
    _, predicted = torch.max(outputs.data, 1)
    correctval += (predicted == labels).sum().item()
    iteration+=1
    tempvalloss+=loss.item()

  val_loss.append(tempvalloss/iteration)
  val_acc.append(correctval/100)
  print('Epoch [',epoch+1,'/',epochs,'] : completed.')
```

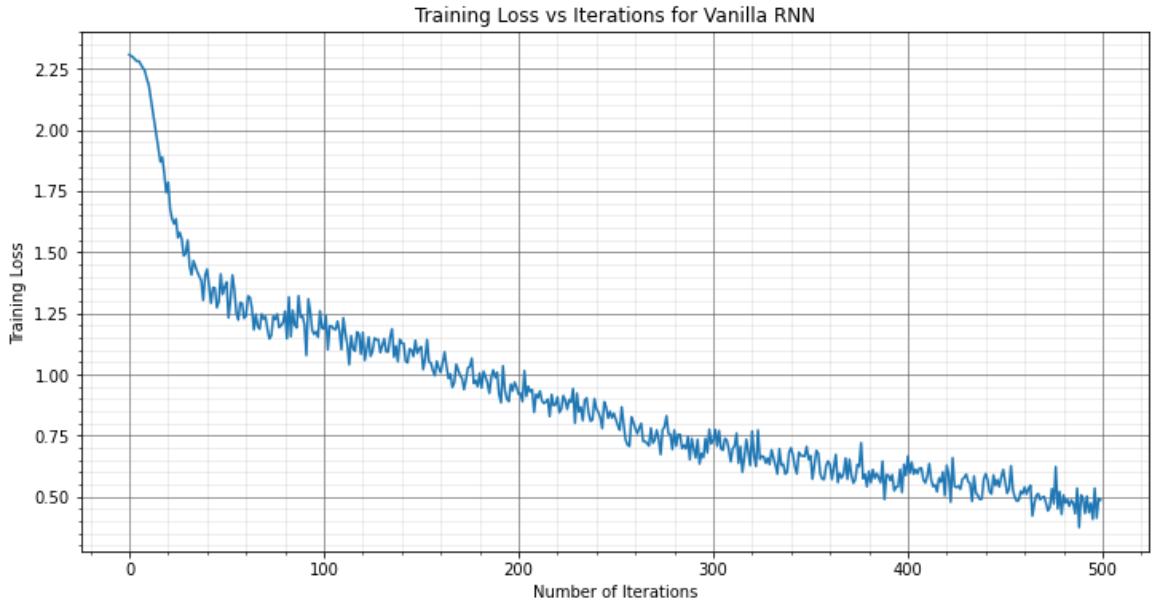
```
Epoch [ 1 / 5 ] : completed.
Epoch [ 2 / 5 ] : completed.
Epoch [ 3 / 5 ] : completed.
Epoch [ 4 / 5 ] : completed.
Epoch [ 5 / 5 ] : completed.
```

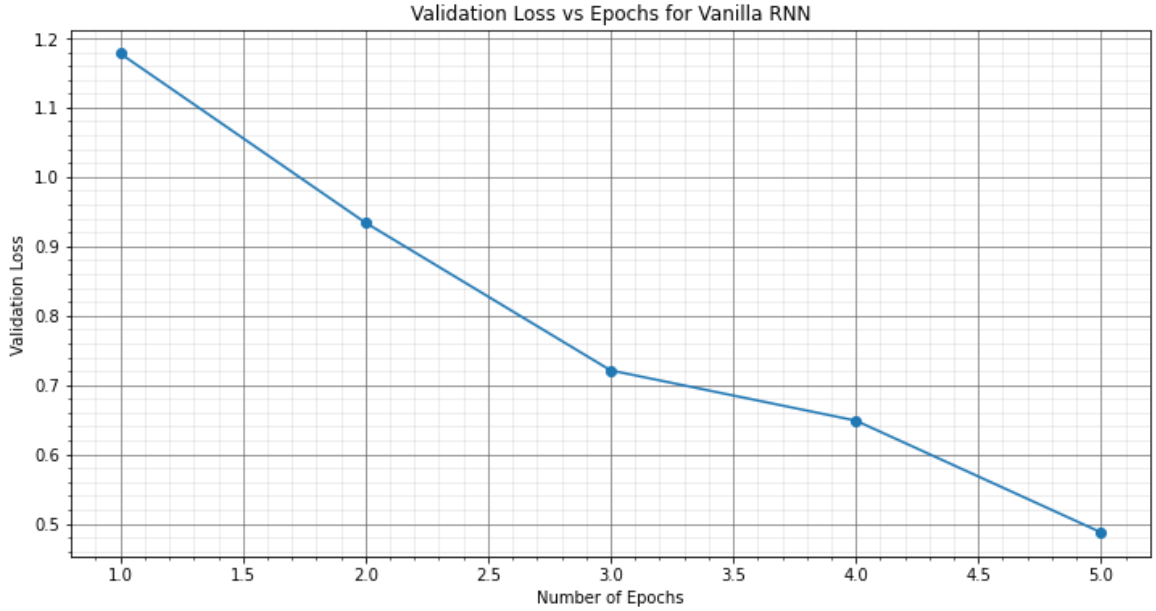
In [35]:

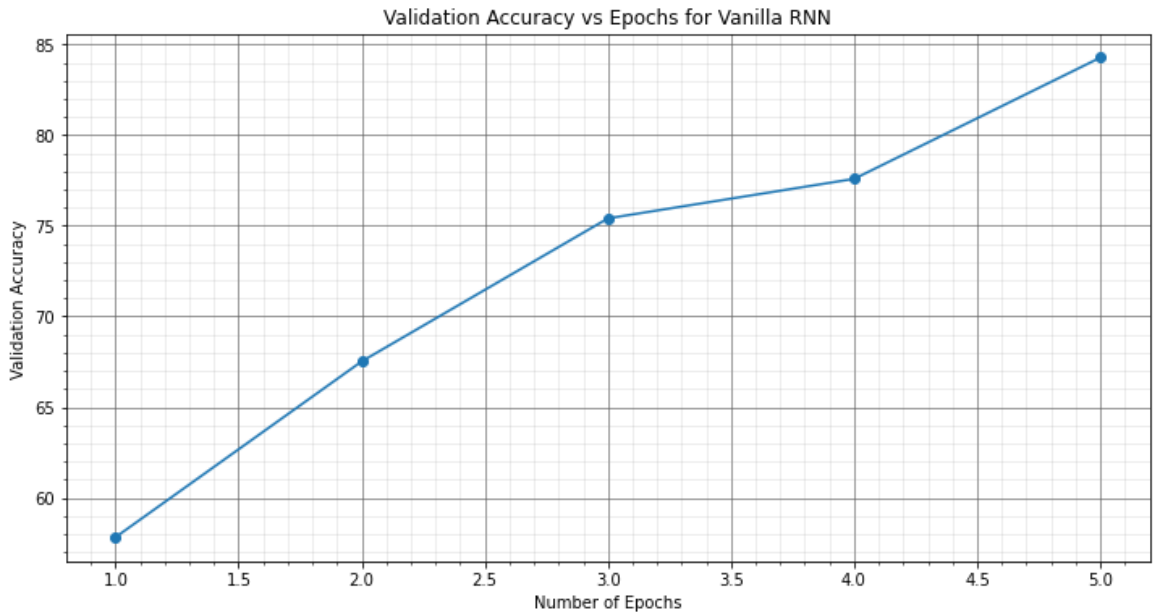
```
def plotter(training_loss,validation_loss,validation_accuracy,model_type):
  plt_1 = plt.figure(figsize=(12, 6))
  plt.figure(1)
  xtrainloss=np.arange(len(training_loss))
  plt.plot(xtrainloss,training_loss)
  plt.grid(b=True, which='major', color='#666666', linestyle='-',alpha=0.8)
  plt.minorticks_on()
  plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)#, c
olor='#999999', linestyle='-', alpha=0.2
  plt.xlabel('Number of Iterations')
  plt.ylabel('Training Loss')
  plt.title('Training Loss vs Iterations for ' +str(model_type))

  plt_1 = plt.figure(figsize=(12, 6))
  plt.figure(2)
  plt.plot(range(1,len(validation_loss)+1),validation_loss,marker='o')
  plt.grid(b=True, which='major', color='#666666', linestyle='-',alpha=0.8)
  plt.minorticks_on()
  plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
  plt.xlabel('Number of Epochs')
  plt.ylabel('Validation Loss')
  plt.title('Validation Loss vs Epochs for ' +str(model_type))

  plt_1 = plt.figure(figsize=(12, 6))
  plt.figure(3)
  plt.plot(range(1,len(validation_accuracy)+1),validation_accuracy,marker='o')
  plt.grid(b=True, which='major', color='#666666', linestyle='-',alpha=0.8)
  plt.minorticks_on()
  plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
  plt.xlabel('Number of Epochs')
  plt.ylabel('Validation Accuracy')
  plt.title('Validation Accuracy vs Epochs for ' +str(model_type))

  plt.show()
```

In [36]:

```
plotter(train_loss,val_loss,val_acc,"Vanilla RNN")
```


Training Loss vs Iterations for Vanilla RNN
Training Loss
Number of Iterations
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0
100
200
300
400
500


Validation Loss vs Epochs for Vanilla RNN
Validation Loss
Number of Epochs
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0


Validation Accuracy vs Epochs for Vanilla RNN
Validation Accuracy
Number of Epochs
85
80
75
70
65
60
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0

In [37]:

```
model1.eval()
with torch.no_grad():
    correct = 0
    total = 0
    for images, labels in testloader:
      images = images.reshape(-1, 28, 28)
      outputs = model1(images)
      _, predicted = torch.max(outputs.data, 1)
      total += labels.size(0)
      correct += (predicted == labels).sum().item()

    print('Test Accuracy of the vanilla RNN model: {:.3f} %'.format((correct / t
otal) * 100))
```

```
Test Accuracy of the vanilla RNN model: 84.690 %
```

LSTM

In [39]:

```
class LSTM(nn.Module):
  def __init__(self):
    super(LSTM, self).__init__()
    self.lstm = nn.LSTM(28,128)
    self.layer2 = nn.Linear(128, 10)

  def forward(self, X):
    hiddenstate=torch.zeros(1,X.size(0),128)
    cellstate=torch.zeros(1,X.size(0),128)
    X=X.permute(1,0,2)
    out,(hs,cs) = self.lstm(X,(hiddenstate,cellstate))
    out = self.layer2(out[27])
    return out.reshape(500,10)
```

In [40]:

```
learning_rate = 0.001
epochs = 5
criterion2 = nn.CrossEntropyLoss()
```

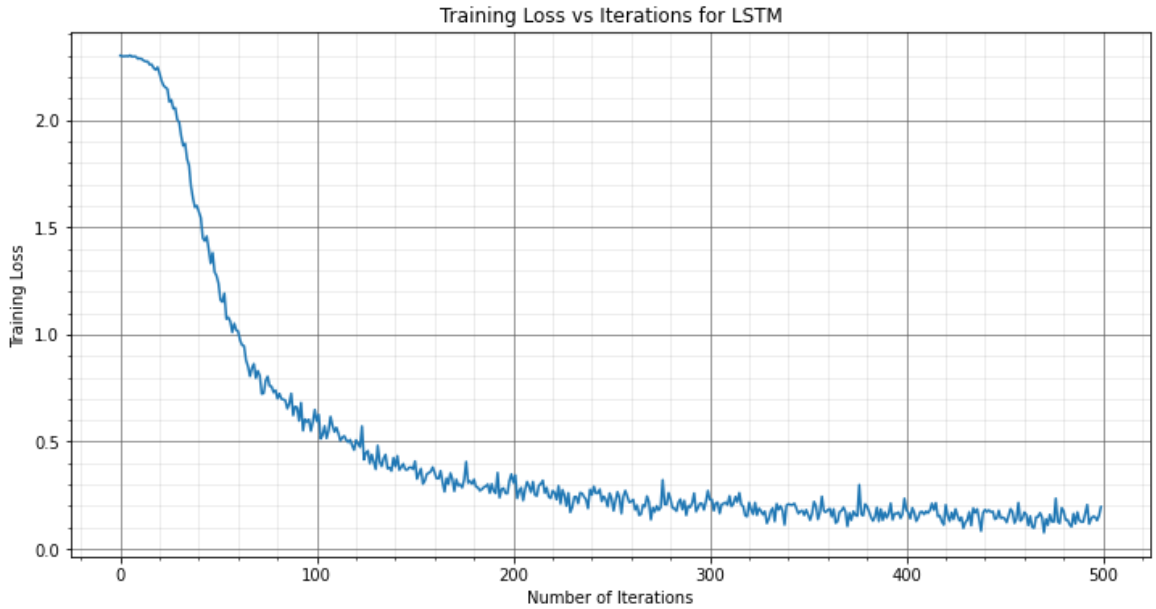
In [41]:

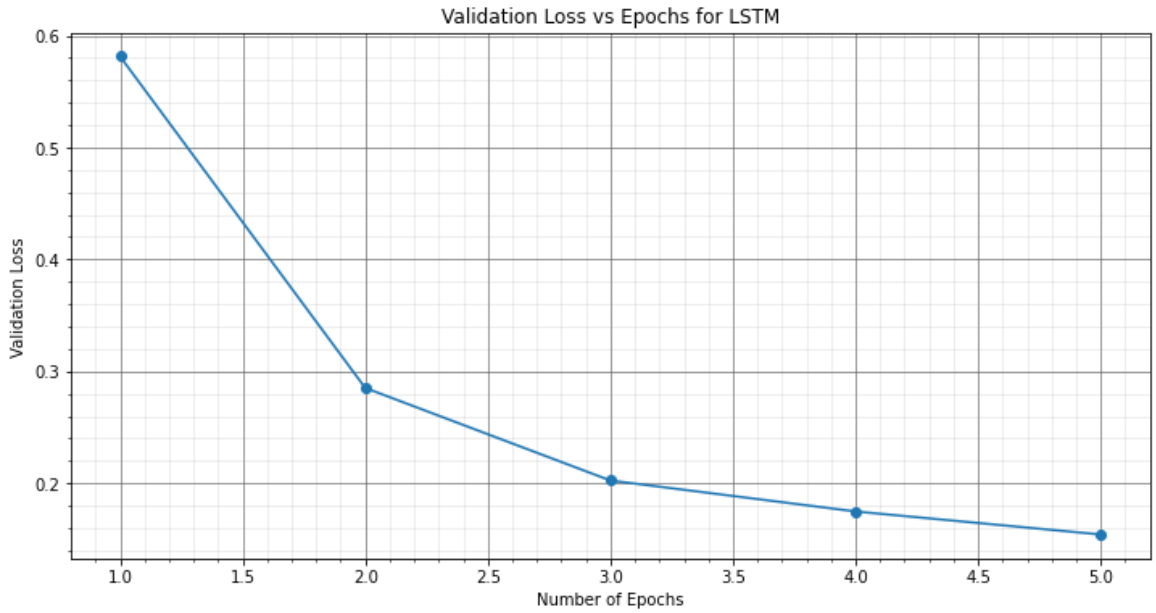
```
train_loss = []
val_loss = []
val_acc = []

model2=LSTM()
optimizer2 = torch.optim.Adam(model2.parameters(), lr=learning_rate)

for epoch in range(epochs):
  for i, (images, labels) in enumerate(trainloader):
    images = images.reshape(-1, 28, 28)
    outputs = model2(images)
    loss = criterion2(outputs, labels)
    train_loss.append(loss.item())

    optimizer2.zero_grad()
    loss.backward()
    optimizer2.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for images, labels in valloader:
    images = images.reshape(-1, 28, 28)
    outputs = model2(images)
    loss = criterion2(outputs, labels)
    _, predicted = torch.max(outputs.data, 1)
    correctval += (predicted == labels).sum().item()
    iteration+=1
    tempvalloss+=loss.item()

  val_loss.append(tempvalloss/iteration)
  val_acc.append(correctval/100)
  print('Epoch [',epoch+1,'/',epochs,'] : completed.')
```

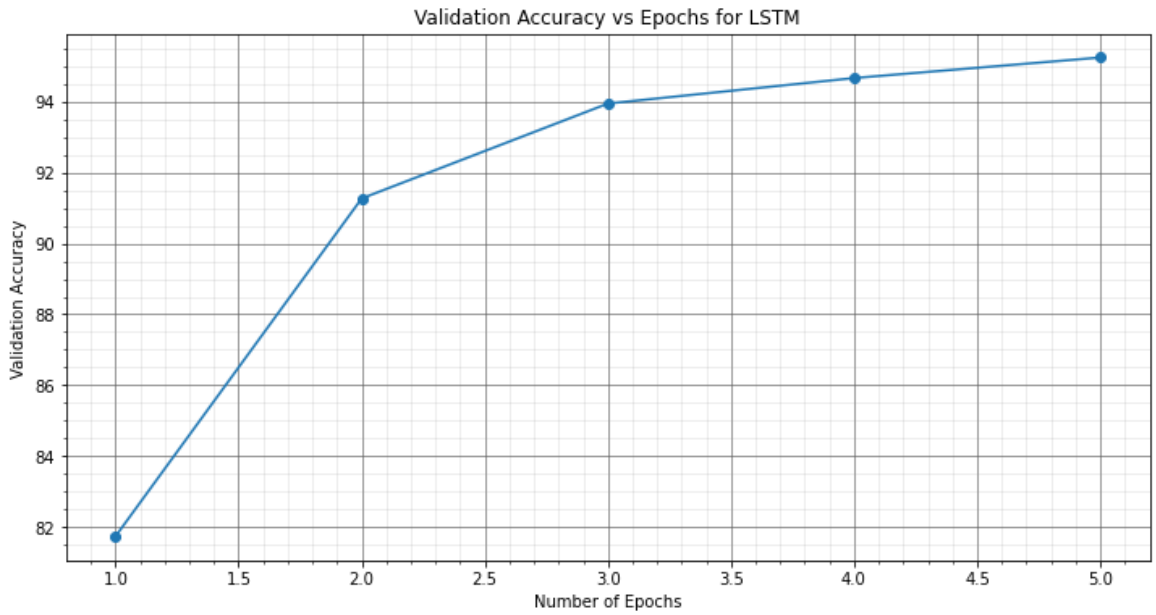
```
Epoch [ 1 / 5 ] : completed.
Epoch [ 2 / 5 ] : completed.
Epoch [ 3 / 5 ] : completed.
Epoch [ 4 / 5 ] : completed.
Epoch [ 5 / 5 ] : completed.
```

In [42]:

```
plotter(train_loss,val_loss,val_acc,"LSTM")
```


Training Loss vs Iterations for LSTM
Training Loss
Number of Iterations
0.0
0.5
1.0
1.5
2.0
0
100
200
300
400
500


Validation Loss vs Epochs for LSTM
Validation Loss
Number of Epochs
0.2
0.3
0.4
0.5
0.6
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0



In [43]:

```
model2.eval()
with torch.no_grad():
    correct = 0
    total = 0
    for images, labels in testloader:
      images = images.reshape(-1, 28, 28)
      outputs = model2(images)
      _, predicted = torch.max(outputs.data, 1)
      total += labels.size(0)
      correct += (predicted == labels).sum().item()

    print('Test Accuracy of LSTM model: {} %'.format((correct / total) * 100))
```

```
Test Accuracy of LSTM model: 95.26 %
```

Bidirectional RNN

In [47]:

```
class Bi_RNN(nn.Module):
  def __init__(self):
    super(Bi_RNN, self).__init__()
    self.rnn = nn.RNN(28,128,1,bidirectional=True)
    self.layer2 = nn.Linear(128*2, 10)

  def forward(self, X):
    X = X.permute(1, 0, 2)
    hiddenlayer=torch.zeros(2,X.size(1),128)
    _,hiddenlayer = self.rnn(X,hiddenlayer)
    finp,binp=hiddenlayer[0],hiddenlayer[1]
    inp=torch.cat((finp,binp),dim=-1)
    out = self.layer2(inp)
    return out
```

In [48]:

```
learning_rate = 0.001
epochs = 5
criterion3 = nn.CrossEntropyLoss()
```

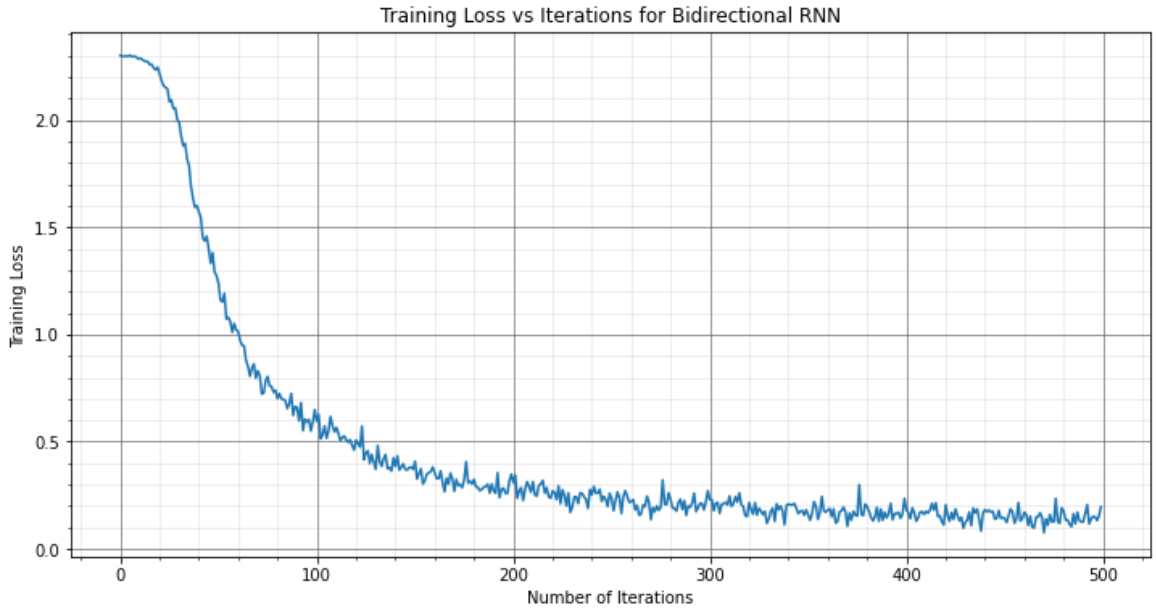
In [49]:

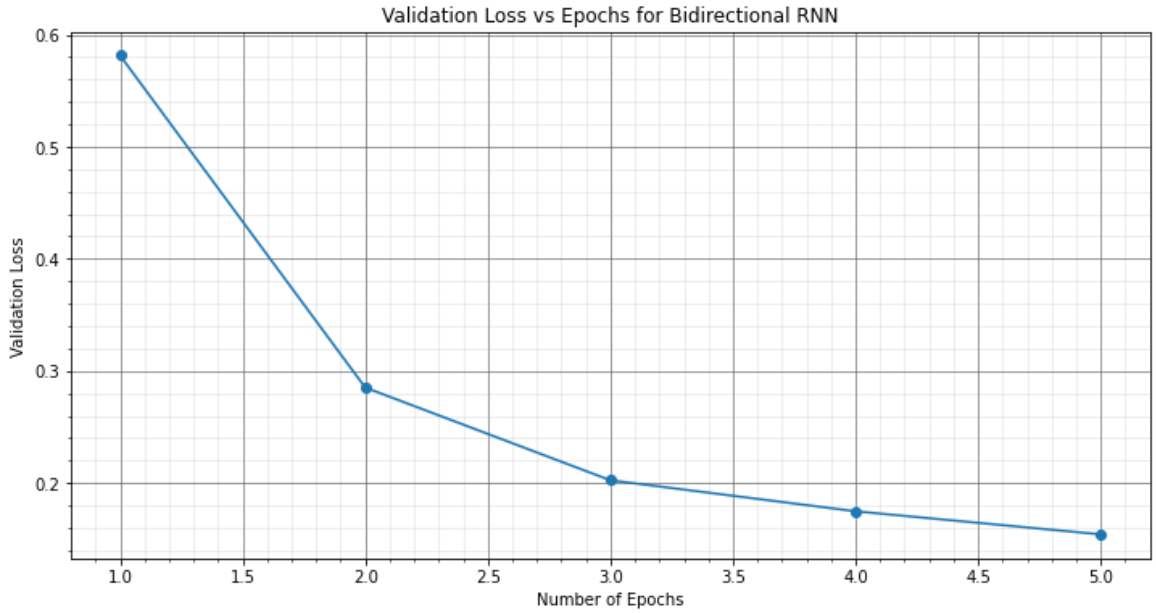
```
trainingloss_list = []
validationloss_list = []
validationaccuracy_list = []
model3=Bi_RNN()
optimizer3 = torch.optim.Adam(model3.parameters(), lr=learning_rate)

for epoch in range(epochs):
  for i, (images, labels) in enumerate(trainloader):
    images = images.reshape(-1, 28, 28)
    outputs = model3(images)
    loss = criterion3(outputs, labels)
    trainingloss_list.append(loss.item())

    optimizer3.zero_grad()
    loss.backward()
    optimizer3.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for images, labels in valloader:
    images = images.reshape(-1, 28, 28)
    outputs = model3(images)
    loss = criterion3(outputs, labels)
    _, predicted = torch.max(outputs.data, 1)
    correctval += (predicted == labels).sum().item()
    iteration+=1
    tempvalloss+=loss.item()

  validationloss_list.append(tempvalloss/iteration)
  validationaccuracy_list.append(correctval/100)
  print('Epoch [',epoch+1,'/',epochs,'] : completed.')
```

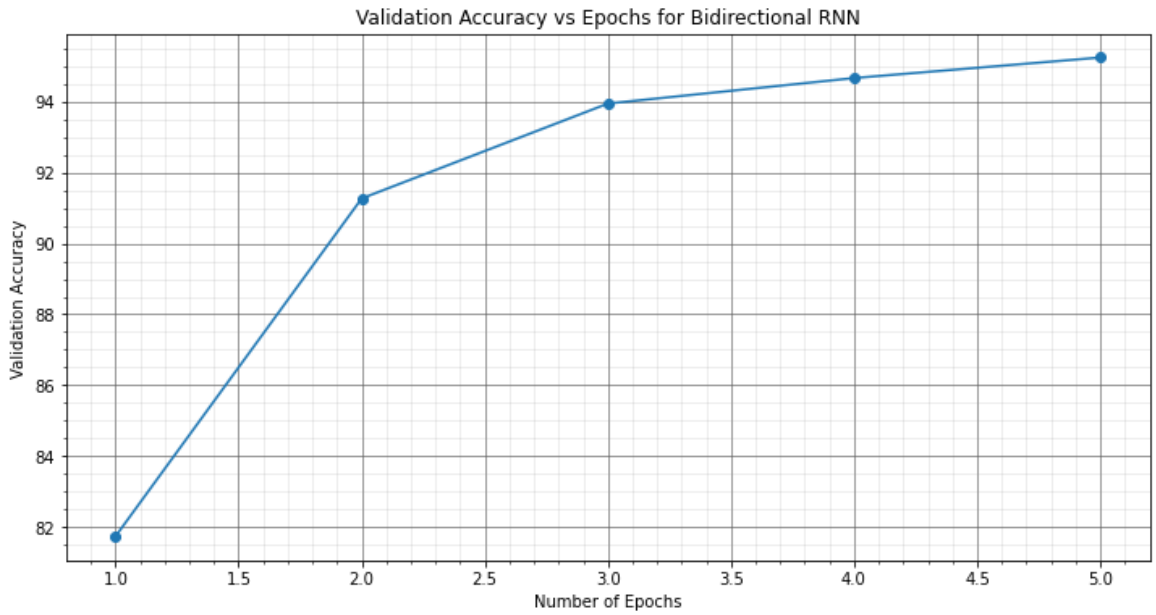
```
Epoch [ 1 / 5 ] : completed.
Epoch [ 2 / 5 ] : completed.
Epoch [ 3 / 5 ] : completed.
Epoch [ 4 / 5 ] : completed.
Epoch [ 5 / 5 ] : completed.
```

In [50]:

```
plotter(train_loss,val_loss,val_acc, "Bidirectional RNN")
```


Training Loss vs Iterations for Bidirectional RNN
Training Loss
Number of Iterations
0.0
0.5
1.0
1.5
2.0
0
100
200
300
400
500


Validation Loss vs Epochs for Bidirectional RNN
Validation Loss
Number of Epochs
0.2
0.3
0.4
0.5
0.6
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0



In [51]:

```
model3.eval()
with torch.no_grad():
    correct = 0
    total = 0
    for images, labels in testloader:
      # print(images.shape)
      images = images.reshape(-1, 28, 28)
      outputs = model3(images)
      _, predicted = torch.max(outputs.data, 1)
      total += labels.size(0)
      correct += (predicted == labels).sum().item()

    print('Test Accuracy of Bidirectional RNN model: {} %'.format((correct / tot
al) * 100))
```

```
Test Accuracy of Bidirectional RNN model: 93.31 %
```

In [60]:

```
ix=1
a=(5*np.abs(np.random.rand(5))).astype(int)
predict=np.zeros(5)
actual=np.zeros(5)
fig,ax = plt.subplots()
for i in range(5):
  ax=plt.subplot(1,5,ix)
  ax.set_xticks([])
  ax.set_yticks([])
  im=ax.imshow(images[a[i]],cmap='gray')
  _,predicted=torch.max(model2(images)[a[i]],0)
  predict[i]=predicted.item()
  actual[i]=labels[a[i]]
  ix+=1
plt.show
print('Prediction:',predict)
print('Real label:',actual)
print('Images:')
```

```
Prediction: [9. 8. 3. 3. 3.]
Real label: [9. 8. 3. 3. 3.]
Images:
```

QUESTION 2

In [61]:

```
def get_rand_list(L):
  ranlist=np.random.randint(0,10,L)
  return ranlist

def getonehot(X):
  x_ohe = np.zeros((len(X), 10))
  x_ohe[np.arange(len(X)), X] = 1
  return x_ohe
```

In [74]:

```
class LSTM_Q2(nn.Module):
  def __init__(self,hidsize):
    super(LSTM_Q2, self).__init__()
    self.hidsize=hidsize
    self.lstm = nn.LSTM(10,hidsize)
    self.layer2 = nn.Linear(hidsize, 10)

  def forward(self, X):
    hiddenstate=torch.zeros(1,X.size(0),self.hidsize)
    cellstate=torch.zeros(1,X.size(0),self.hidsize)
    X=X.permute(1,0,2)
    out,(hs,cs) = self.lstm(X,(hiddenstate,cellstate))
    out = self.layer2(out[-1])
    return out.reshape(1,10)
```

In [86]:

```
learning_rate = 0.002
epochs = 15
criterion4 = nn.CrossEntropyLoss()
```

In [87]:

```
train_ran_list=[]
val_ran_list=[]
test_ran_list=[]
for i in range(100):
  for j in range(3,11):
    train_ran_list.append(get_rand_list(j))
  L=np.random.randint(3,11)
  val_ran_list.append(get_rand_list(L))
  L=np.random.randint(3,11)
  test_ran_list.append(get_rand_list(L))
```

In [88]:

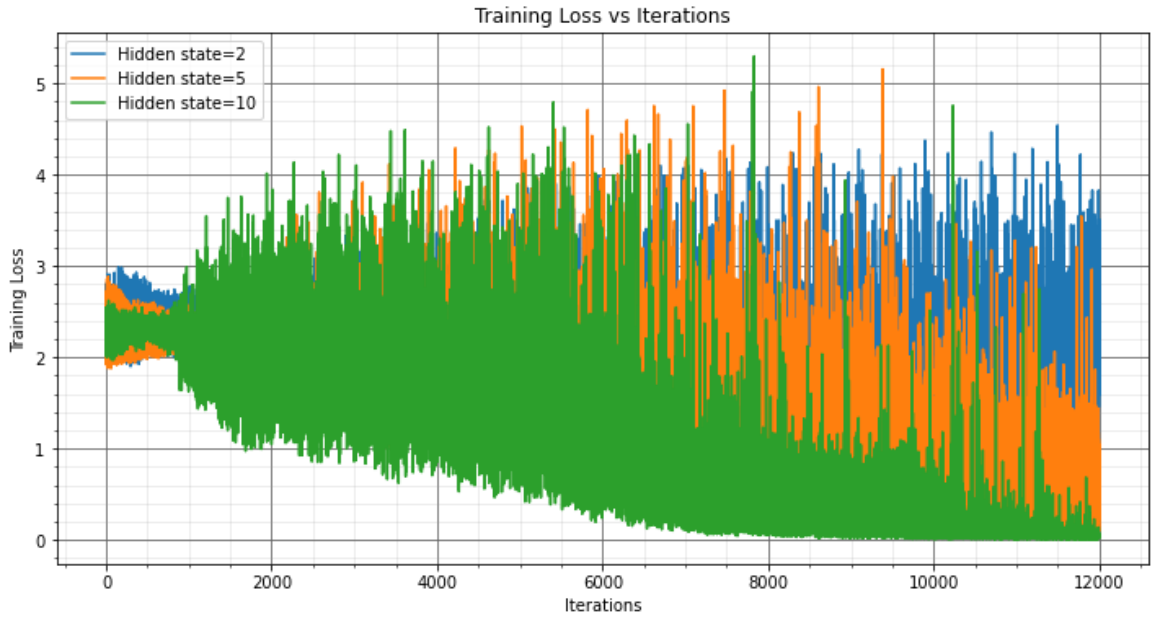
```
K=1
train_loss_2=[]
val_acc_2=[]

train_loss_5=[]
val_acc_5=[]

train_loss_10=[]
val_acc_10=[]

iteration=0
tempvalloss=0
correctval=0

model4_2=LSTM_Q2(2)
optimizer4_2 = torch.optim.Adam(model4_2.parameters(), lr=learning_rate)

for epoch in range(epochs):
  for i in range(len(train_ran_list)):
    hotranlist=torch.zeros((1,len(train_ran_list[i]),10))
    hotranlist[0]=torch.from_numpy(getonehot(train_ran_list[i]))

    output=model4_2(hotranlist.float())
    _,predicted=torch.max(output.data,1)

    label=torch.tensor([train_ran_list[i][K]],dtype=torch.long)
    loss = criterion4(output, label.long())
    train_loss_2.append(loss.item())

    optimizer4_2.zero_grad()
    loss.backward()
    optimizer4_2.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(val_ran_list)):
    hotranlist=torch.zeros((1,len(val_ran_list[i]),10))
    hotranlist[0]=torch.from_numpy(getonehot(val_ran_list[i]))

    output=model4_2(hotranlist.float())
    _,predicted=torch.max(output.data,1)

    label=torch.tensor([val_ran_list[i][K]],dtype=torch.long)
    _, predicted = torch.max(output.data, 1)
    correctval += (predicted == label).sum().item()
    iteration+=1

  val_acc_2.append(correctval/len(val_ran_list)*100)


model4_5=LSTM_Q2(5)
optimizer4_5 = torch.optim.Adam(model4_5.parameters(), lr=learning_rate)

for epoch in range(epochs):
  for i in range(len(train_ran_list)):
    hotranlist=torch.zeros((1,len(train_ran_list[i]),10))
    hotranlist[0]=torch.from_numpy(getonehot(train_ran_list[i]))
```

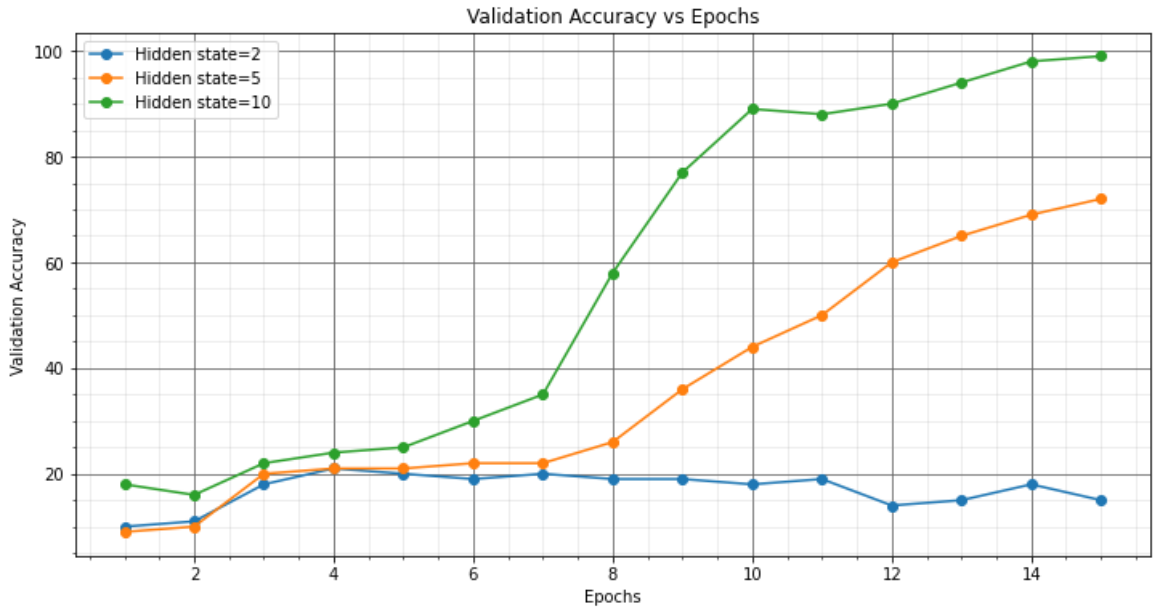
```
    output=model4_5(hotranlist.float())
    _,predicted=torch.max(output.data,1)

    label=torch.tensor([train_ran_list[i][K]],dtype=torch.long)
    loss = criterion4(output, label.long())
    train_loss_5.append(loss.item())

    optimizer4_5.zero_grad()
    loss.backward()
    optimizer4_5.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(val_ran_list)):
    hotranlist=torch.zeros((1,len(val_ran_list[i]),10))
    hotranlist[0]=torch.from_numpy(getonehot(val_ran_list[i]))

    output=model4_5(hotranlist.float())
    _,predicted=torch.max(output.data,1)

    label=torch.tensor([val_ran_list[i][K]],dtype=torch.long)
    _, predicted = torch.max(output.data, 1)
    correctval += (predicted == label).sum().item()
    iteration+=1

  val_acc_5.append(correctval/len(val_ran_list)*100)


model4_10=LSTM_Q2(10)
optimizer4_10 = torch.optim.Adam(model4_10.parameters(), lr=learning_rate)

for epoch in range(epochs):
  for i in range(len(train_ran_list)):
    hotranlist=torch.zeros((1,len(train_ran_list[i]),10))
    hotranlist[0]=torch.from_numpy(getonehot(train_ran_list[i]))

    output=model4_10(hotranlist.float())
    _,predicted=torch.max(output.data,1)

    label=torch.tensor([train_ran_list[i][K]],dtype=torch.long)
    loss = criterion4(output, label.long())
    train_loss_10.append(loss.item())

    optimizer4_10.zero_grad()
    loss.backward()
    optimizer4_10.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(val_ran_list)):
    hotranlist=torch.zeros((1,len(val_ran_list[i]),10))
    hotranlist[0]=torch.from_numpy(getonehot(val_ran_list[i]))

    output=model4_10(hotranlist.float())
    _,predicted=torch.max(output.data,1)
```

```
    label=torch.tensor([val_ran_list[i][K]],dtype=torch.long)
    _, predicted = torch.max(output.data, 1)
    correctval += (predicted == label).sum().item()
    iteration+=1

  val_acc_10.append(correctval/len(val_ran_list)*100)
```

In [89]:

```
plt_1 = plt.figure(figsize=(12, 6))
plt.figure(1)
xtrainloss=np.arange(len(train_loss_2))
plt.plot(xtrainloss,train_loss_2,label="Hidden state=2")
plt.plot(xtrainloss,train_loss_5,label="Hidden state=5")
plt.plot(xtrainloss,train_loss_10,label="Hidden state=10")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Training Loss')
plt.title('Training Loss vs Iterations')
plt.legend()

plt_1 = plt.figure(figsize=(12, 6))
plt.figure(2)
xvalloss=range(1,len(val_acc_2)+1)
plt.plot(xvalloss,val_acc_2,label="Hidden state=2",marker='o')
plt.plot(xvalloss,val_acc_5,label="Hidden state=5",marker='o')
plt.plot(xvalloss,val_acc_10,label="Hidden state=10",marker='o')
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-',alpha=0.2)
plt.xlabel('Epochs')
plt.ylabel('Validation Accuracy')
plt.title('Validation Accuracy vs Epochs')
plt.legend()
plt.show()
```


Training Loss vs Iterations
Hidden state=2
Hidden state=5
Hidden state=10
Training Loss
Iterations
0
1
2
3
4
5
0
2000
4000
6000
8000
10000
12000


Validation Accuracy vs Epochs
Hidden state=2
Hidden state=5
Hidden state=10
Validation Accuracy
Epochs
20
40
60
80
100
2
4
6
8
10
12
14

In [90]:

```
model4_2.eval()
with torch.no_grad():
    correct = 0
    total = 0
    for i in range(len(test_ran_list)):
      hotranlist=torch.zeros((1,len(test_ran_list[i]),10))
      hotranlist[0]=torch.from_numpy(getonehot(test_ran_list[i]))
      output=model4_2(hotranlist.float())
      label=torch.tensor([test_ran_list[i][K]],dtype=torch.long)
      _, predicted = torch.max(output.data, 1)
      correct += (predicted == label).sum().item()

    print('Test Accuracy of the model with 2 hidden states on the 100 test sampl
es: {} %'.format((correct / len(test_ran_list)) * 100))

model4_5.eval()
with torch.no_grad():
    correct = 0
    total = 0
    for i in range(len(test_ran_list)):
      hotranlist=torch.zeros((1,len(test_ran_list[i]),10))
      hotranlist[0]=torch.from_numpy(getonehot(test_ran_list[i]))
      output=model4_5(hotranlist.float())
      label=torch.tensor([test_ran_list[i][K]],dtype=torch.long)
      _, predicted = torch.max(output.data, 1)
      correct += (predicted == label).sum().item()

    print('Test Accuracy of the model with 5 hidden states on the 100 test sampl
es: {} %'.format((correct / len(test_ran_list)) * 100))

model4_10.eval()
with torch.no_grad():
    correct = 0
    total = 0
    for i in range(len(test_ran_list)):
      hotranlist=torch.zeros((1,len(test_ran_list[i]),10))
      hotranlist[0]=torch.from_numpy(getonehot(test_ran_list[i]))
      output=model4_10(hotranlist.float())
      label=torch.tensor([test_ran_list[i][K]],dtype=torch.long)
      _, predicted = torch.max(output.data, 1)
      correct += (predicted == label).sum().item()

    print('Test Accuracy of the model with 10 hidden states on the 100 test samp
les: {} %'.format((correct / len(test_ran_list)) * 100))
```

```
Test Accuracy of the model with 2 hidden states on the 100 test samp
les: 19.0 %
Test Accuracy of the model with 5 hidden states on the 100 test samp
les: 69.0 %
Test Accuracy of the model with 10 hidden states on the 100 test sam
ples: 99.0 %
```

In [91]:

```
for i in range(3,11):
  print("For Length",i)
  for j in range(3):
      a=get_rand_list(i)
      hotranlist=torch.zeros((1,len(a),10))
      hotranlist[0]=torch.from_numpy(getonehot(a))
      output=model4_10(hotranlist.float())
      label=torch.tensor([a[K]],dtype=torch.long)
      _, predicted = torch.max(output.data, 1)
      print("Array:",a,"Prediction at position 2:",predicted.item())
```

```
For Length 3
Array: [1 2 9] Prediction at position 2: 2
Array: [0 4 9] Prediction at position 2: 4
Array: [9 5 3] Prediction at position 2: 5
For Length 4
Array: [8 0 8 7] Prediction at position 2: 0
Array: [2 9 9 1] Prediction at position 2: 9
Array: [2 9 1 6] Prediction at position 2: 9
For Length 5
Array: [6 7 2 2 0] Prediction at position 2: 7
Array: [8 3 7 4 8] Prediction at position 2: 3
Array: [8 9 0 4 8] Prediction at position 2: 9
For Length 6
Array: [7 6 5 4 6 1] Prediction at position 2: 6
Array: [6 2 1 5 6 9] Prediction at position 2: 2
Array: [0 3 0 2 3 7] Prediction at position 2: 3
For Length 7
Array: [1 1 1 7 5 1 2] Prediction at position 2: 1
Array: [6 6 6 5 5 5 2] Prediction at position 2: 6
Array: [9 2 6 1 6 2 4] Prediction at position 2: 2
For Length 8
Array: [8 6 9 3 9 7 6 1] Prediction at position 2: 6
Array: [5 9 1 5 0 3 8 9] Prediction at position 2: 5
Array: [6 6 8 9 1 2 2 9] Prediction at position 2: 6
For Length 9
Array: [7 1 4 2 5 7 7 9 1] Prediction at position 2: 1
Array: [3 8 0 1 0 5 9 7 2] Prediction at position 2: 8
Array: [3 3 5 4 9 4 5 0 9] Prediction at position 2: 3
For Length 10
Array: [2 7 7 4 4 6 8 3 9 9] Prediction at position 2: 7
Array: [1 4 1 0 1 9 2 9 8 2] Prediction at position 2: 4
Array: [7 5 8 4 0 3 3 0 4 6] Prediction at position 2: 5
```

QUESTION 3

In [24]:

```
def bin_generator(L):
  N1=np.random.randint(0,2**(L-1))
  N2=np.random.randint(0,2**(L-1))
  S=N1+N2
  binlen=L
  B1=np.zeros((1,binlen))
  B2=np.zeros((1,binlen))
  B3=np.zeros((binlen))
  b=np.flip(np.array(list(np.binary_repr(N1)), dtype=int))
  B1[0][0:len(b)]=b[0:]
  b=np.flip(np.array(list(np.binary_repr(N2)), dtype=int))
  B2[0][0:len(b)]=b[0:]
  b=np.flip(np.array(list(np.binary_repr(S)), dtype=int))
  B3[0:len(b)]=b[0:]
  return(np.concatenate((np.transpose(B1),np.transpose(B2)),axis=1),B3)
```

In [37]:

```
train_X=[]
train_Y=[]
for i in range(250):
  L=np.random.randint(1,21)
  a,b=bin_generator(L)
  train_X.append(a)
  train_Y.append(b)

val_X=[]
val_Y=[]
for i in range(100):
  L=np.random.randint(1,21)
  a,b=bin_generator(L)
  val_X.append(a)
  val_Y.append(b)

test_X=[]
test_Y=[]
for j in range(1,21):
  for i in range(100):
    a,b=bin_generator(j)
    test_X.append(a)
    test_Y.append(b)
```

In [26]:

```
class LSTM_Q3(nn.Module):
  def __init__(self,hidsize):
    super(LSTM_Q3, self).__init__()
    self.hidsize=hidsize
    self.lstm = nn.LSTM(2,hidsize)
    self.layer2 = nn.Sequential(
        nn.Linear(hidsize,1),
        nn.Sigmoid())

  def forward(self, X):
    X=X.permute(1,0,2)
    hiddenstate=torch.zeros(1,X.size(1),self.hidsize)
    cellstate=torch.zeros(1,X.size(1),self.hidsize)
    out,(hs,cs) = self.lstm(X,(hiddenstate,cellstate))
    out = self.layer2(out)
    return out.reshape(X.size(0))
```

In [136]:

```
learning_rate = 0.1
epochs = 5
criterion5 = nn.MSELoss()
model5_3=LSTM_Q3(3)#model51=model5_3
optimizer5_3 = torch.optim.Adam(model5_3.parameters(), lr=learning_rate)
model5_10=LSTM_Q3(10)#model52=model5_10
optimizer5_10 = torch.optim.Adam(model5_10.parameters(), lr=learning_rate)
```

In [141]:

```
train_loss_3=[]
val_loss_3=[]
val_acc_3=[]
for epoch in range(epochs):
  for i in range(int(len(train_X))):
    a=torch.zeros((1,train_X[i].shape[0],train_X[i].shape[1]))
    a[0]=torch.from_numpy(train_X[i])
    output=model5_3(a.float())
    label=torch.tensor(np.transpose(train_Y[i]))
    loss = criterion5(output,label.float())
    train_loss_3.append(loss.item())

    optimizer5_3.zero_grad()
    loss.backward()
    optimizer5_3.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(val_X)):
    correct=0
    a=torch.zeros((1,val_X[i].shape[0],val_X[i].shape[1]))
    a[0]=torch.from_numpy(val_X[i])
    output=model5_3(a.float())
    label=torch.tensor(np.transpose(val_Y[i]))
    loss = criterion5(output,label.float())
    iteration+=1
    tempvalloss+=loss.item()

    predicted=torch.zeros(output.shape)
    predicted[output>=0.5]=1
    predicted[output<0.5]=0
    correct += (predicted == label.float()).sum().item()/len(label)

  val_acc_3.append(100*correct/iteration)
  val_loss_3.append(tempvalloss/iteration)
  print('Epoch [',epoch+1,'/',epochs,'] : completed.')
```

```
Epoch [ 1 / 5 ] : completed.
Epoch [ 2 / 5 ] : completed.
Epoch [ 3 / 5 ] : completed.
Epoch [ 4 / 5 ] : completed.
Epoch [ 5 / 5 ] : completed.
```

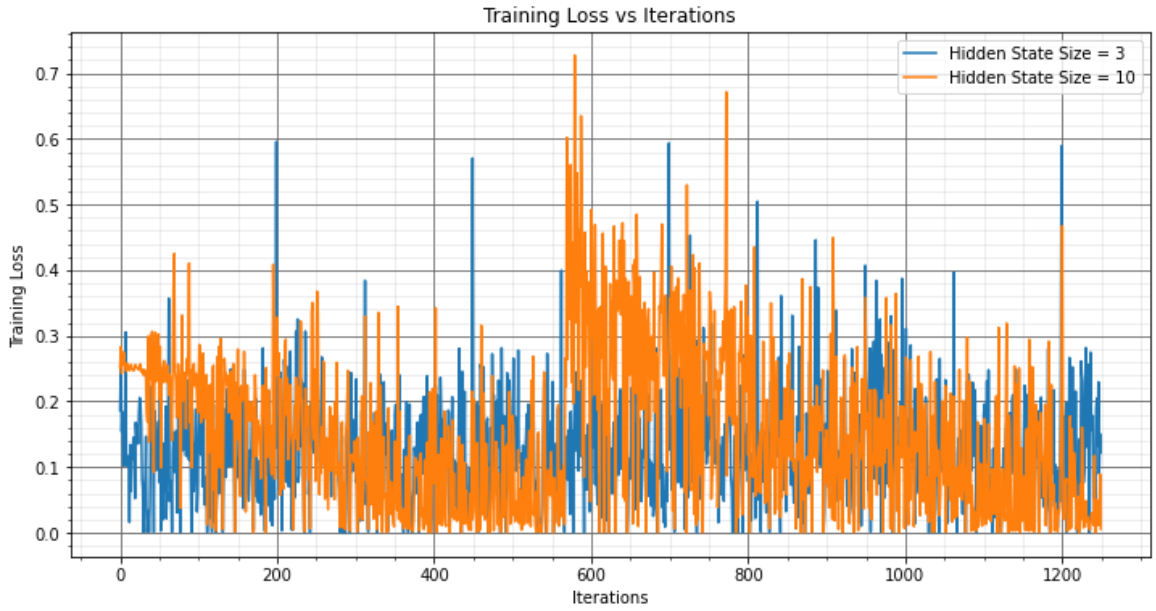
In [138]:

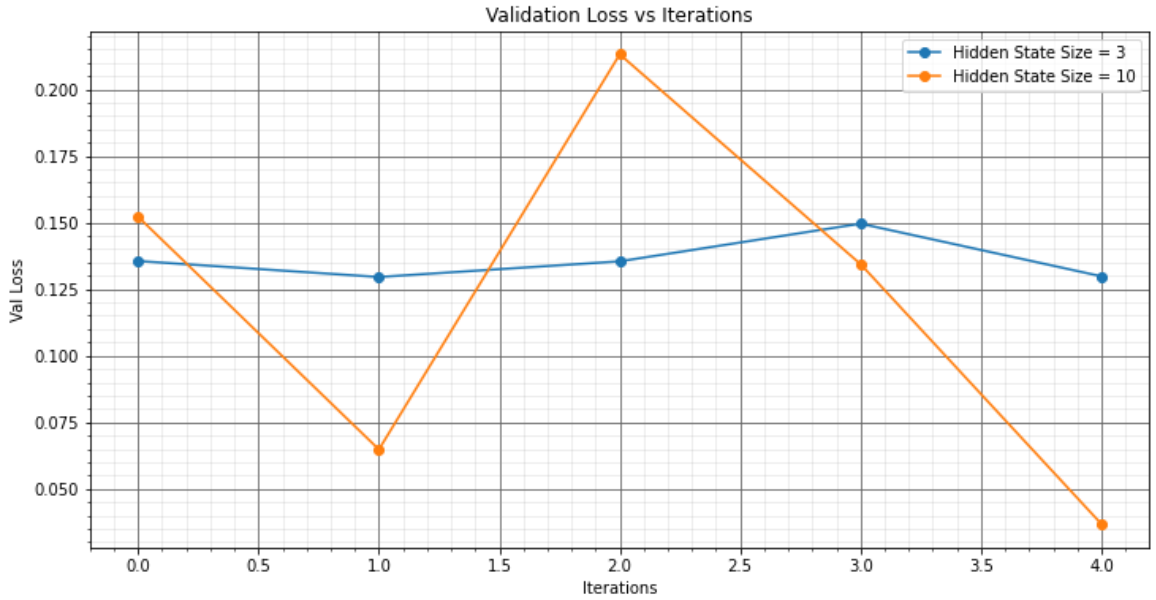
```
train_loss_10=[]
val_loss_10=[]
val_acc_10=[]
for epoch in range(epochs):
  for i in range(len(train_X)):
    a=torch.zeros((1,train_X[i].shape[0],train_X[i].shape[1]))
    a[0]=torch.from_numpy(train_X[i])
    output=model5_10(a.float())
    label=torch.tensor(np.transpose(train_Y[i]))
    loss = criterion5(output,label.float())
    train_loss_10.append(loss.item())

    optimizer5_10.zero_grad()
    loss.backward()
    optimizer5_10.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(val_X)):
    correct=0
    a=torch.zeros((1,val_X[i].shape[0],val_X[i].shape[1]))
    a[0]=torch.from_numpy(val_X[i])
    output=model5_10(a.float())
    label=torch.tensor(np.transpose(val_Y[i]))
    loss = criterion5(output,label.float())
    iteration+=1
    tempvalloss+=loss.item()

    predicted=torch.zeros(output.shape)
    predicted[output>=0.5]=1
    predicted[output<0.5]=0
    correct += (predicted == label.float()).sum().item()/len(label)

  val_acc_10.append(100*correct/iteration)
  val_loss_10.append(tempvalloss/iteration)
  print('Epoch [',epoch+1,'/',epochs,'] : completed.')
```

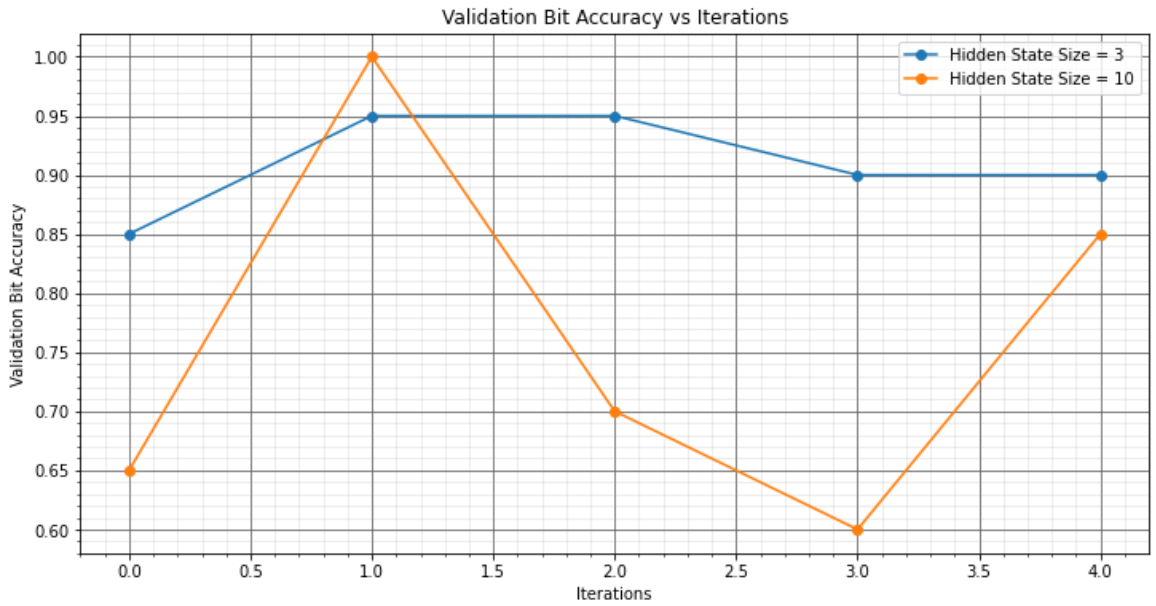
```
Epoch [ 1 / 5 ] : completed.
Epoch [ 2 / 5 ] : completed.
Epoch [ 3 / 5 ] : completed.
Epoch [ 4 / 5 ] : completed.
Epoch [ 5 / 5 ] : completed.
```

In [142]:

```
plt_1 = plt.figure(figsize=(12, 6))
plt.figure(1)
xtrainloss=np.arange(len(train_loss_3))
plt.plot(xtrainloss,train_loss_3,label="Hidden State Size = 3")
plt.plot(xtrainloss,train_loss_10,label="Hidden State Size = 10")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Training Loss')
plt.title('Training Loss vs Iterations')
plt.legend()

plt_1 = plt.figure(figsize=(12, 6))
plt.figure(2)
xtestloss=np.arange(len(val_loss_3))
plt.plot(xtestloss,val_loss_3,label="Hidden State Size = 3",marker='o')
plt.plot(xtestloss,val_loss_10,label="Hidden State Size = 10",marker='o')
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Val Loss')
plt.title('Validation Loss vs Iterations')
plt.legend()

plt_1 = plt.figure(figsize=(12, 6))
plt.figure(3)
xbittrain=np.arange(len(val_acc_3))
plt.plot(xbittrain,val_acc_3,label="Hidden State Size = 3",marker='o')
plt.plot(xbittrain,val_acc_10,label="Hidden State Size = 10",marker='o')
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Validation Bit Accuracy')
plt.title('Validation Bit Accuracy vs Iterations')
plt.legend()


plt.show()
```


Training Loss vs Iterations
Hidden State Size = 3
Hidden State Size = 10
Training Loss
Iterations
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0
200
400
600
800
1000
1200


Validation Loss vs Iterations
Hidden State Size = 3
Hidden State Size = 10
Val Loss
Iterations
0.050
0.075
0.100
0.125
0.150
0.175
0.200
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0



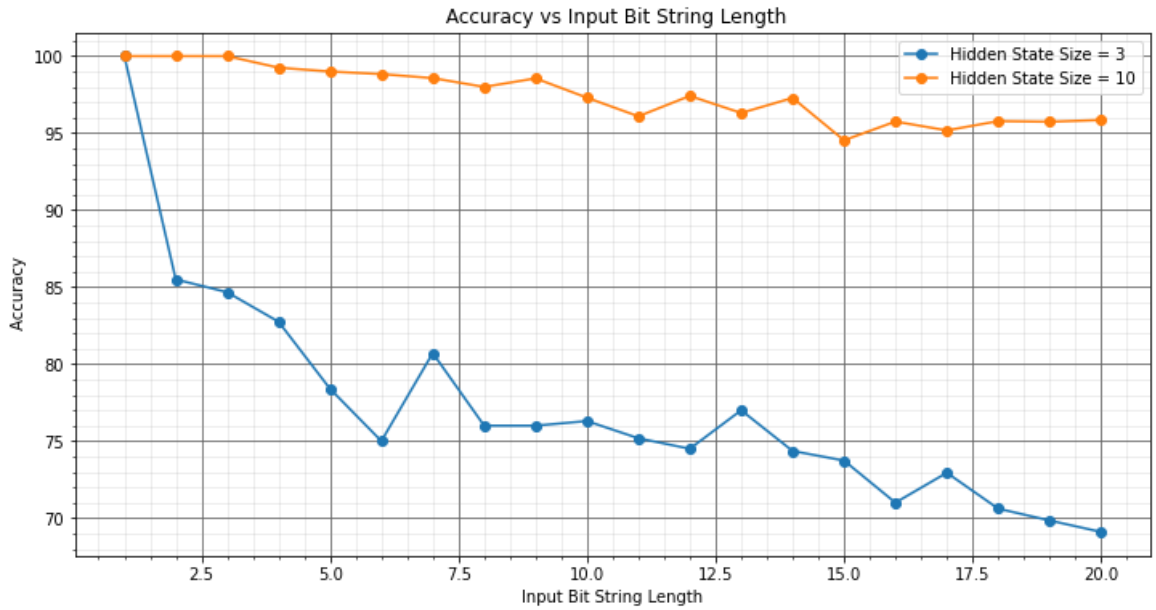
In [149]:

```
model5_3.eval()
correctarr1 = np.zeros(20)
correctarr2 = np.zeros(20)
with torch.no_grad():
    for i in range(len(test_X)):
      a=torch.zeros((1,test_X[i].shape[0],test_X[i].shape[1]))
      a[0]=torch.from_numpy(test_X[i])
      output=model5_3(a.float())
      label=torch.tensor(np.transpose(test_Y[i]))
      predicted=torch.zeros(output.shape)
      predicted[output>=0.5]=1
      predicted[output<0.5]=0
      correctarr1[len(label)-1] += (predicted == label.float()).sum().item()/(le
n(label))


    print('Accuracy for number of hidden states = 3:',(np.sum(correctarr1)/20))

model5_10.eval()
with torch.no_grad():
    for i in range(len(test_X)):
      a=torch.zeros((1,test_X[i].shape[0],test_X[i].shape[1]))
      a[0]=torch.from_numpy(test_X[i])
      output=model5_10(a.float())
      label=torch.tensor(np.transpose(test_Y[i]))
      predicted=torch.zeros(output.shape)
      predicted[output>0.5]=1
      predicted[output<=0.5]=0
      correctarr2[len(label)-1] += (predicted == label.float()).sum().item()/(le
n(label))
    print('Accuracy for number of hidden states = 10:',(np.sum(correctarr2)/20))
```

```
Accuracy for number of hidden states = 3: 77.17988197990518
Accuracy for number of hidden states = 10: 97.47178618079548
```

In [144]:

```
x=np.arange(1,21)
plt_1 = plt.figure(figsize=(12, 6))
plt.figure(1)
plt.plot(x,correctarr1,label="Hidden State Size = 3",marker='o')
plt.plot(x,correctarr2,label="Hidden State Size = 10",marker='o')
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Input Bit String Length')
plt.ylabel(' Accuracy')
plt.title(' Accuracy vs Input Bit String Length')
plt.legend()
plt.show()
```



In [32]:

```
learning_rate = 0.08
epochs = 5
criterion5 = nn.MSELoss()
model5_5_mse=LSTM_Q3(5)
optimizer5_5_mse = torch.optim.Adam(model5_5_mse.parameters(), lr=learning_rate)
model5_5_ce=LSTM_Q3(5)
optimizer5_5_ce = torch.optim.Adam(model5_5_ce.parameters(), lr=learning_rate)
```

In [45]:

```
train_loss_5_mse=[]
val_loss_5_mse=[]
val_acc_5_mse=[]
for epoch in range(epochs):
  for i in range(int(len(train_X))):
    a=torch.zeros((1,train_X[i].shape[0],train_X[i].shape[1]))
    a[0]=torch.from_numpy(train_X[i])
    output=model5_5_mse(a.float())
    label=torch.tensor(np.transpose(train_Y[i]))
    loss = criterion5(output,label.float())
    train_loss_5_mse.append(loss.item())

    optimizer5_5_mse.zero_grad()
    loss.backward()
    optimizer5_5_mse.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(val_X)):
    correct=0
    a=torch.zeros((1,val_X[i].shape[0],val_X[i].shape[1]))
    a[0]=torch.from_numpy(val_X[i])
    output=model5_5_mse(a.float())
    label=torch.tensor(np.transpose(val_Y[i]))
    loss = criterion5(output,label.float())
    iteration+=1
    tempvalloss+=loss.item()

    predicted=torch.zeros(output.shape)
    predicted[output>=0.5]=1
    predicted[output<0.5]=0
    correct += (predicted == label.float()).sum().item()/len(label)

  val_acc_5_mse.append(100*correct/iteration)
  val_loss_5_mse.append(tempvalloss/iteration)
  print('Epoch [',epoch+1,'/',epochs,'] : completed.')
```

```
Epoch [ 1 / 5 ] : completed.
Epoch [ 2 / 5 ] : completed.
Epoch [ 3 / 5 ] : completed.
Epoch [ 4 / 5 ] : completed.
Epoch [ 5 / 5 ] : completed.
```

In [46]:

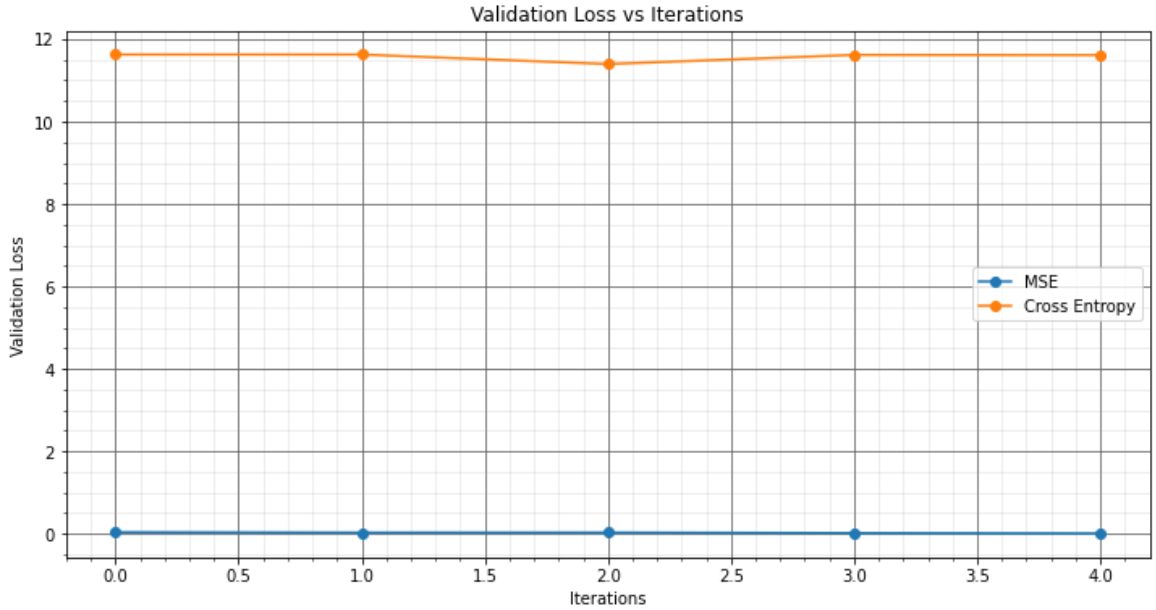
```
criterion5_ce=nn.CrossEntropyLoss()
train_loss_5_ce=[]
val_loss_5_ce=[]
val_acc_5_ce=[]
for epoch in range(epochs):
  for i in range(int(len(train_X))):
    a=torch.zeros((1,train_X[i].shape[0],train_X[i].shape[1]))
    a[0]=torch.from_numpy(train_X[i])
    output=model5_5_ce(a.float())
    label=torch.tensor(np.transpose(train_Y[i]))
    loss=criterion5_ce(output,label.float())
    train_loss_5_ce.append(loss.item())

    optimizer5_5_ce.zero_grad()
    loss.backward()
    optimizer5_5_ce.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(val_X)):
    correct=0
    a=torch.zeros((1,val_X[i].shape[0],val_X[i].shape[1]))
    a[0]=torch.from_numpy(val_X[i])
    output=model5_5_ce(a.float())
    label=torch.tensor(np.transpose(val_Y[i]))
    loss=criterion5_ce(output,label.float())
    iteration+=1
    tempvalloss+=loss.item()

    predicted=torch.zeros(output.shape)
    predicted[output>=0.5]=1
    predicted[output<0.5]=0
    correct += (predicted == label.float()).sum().item()/len(label)

  val_acc_5_ce.append(100*correct/iteration)
  val_loss_5_ce.append(tempvalloss/iteration)
  print('Epoch [',epoch+1,'/',epochs,'] : completed.')
```

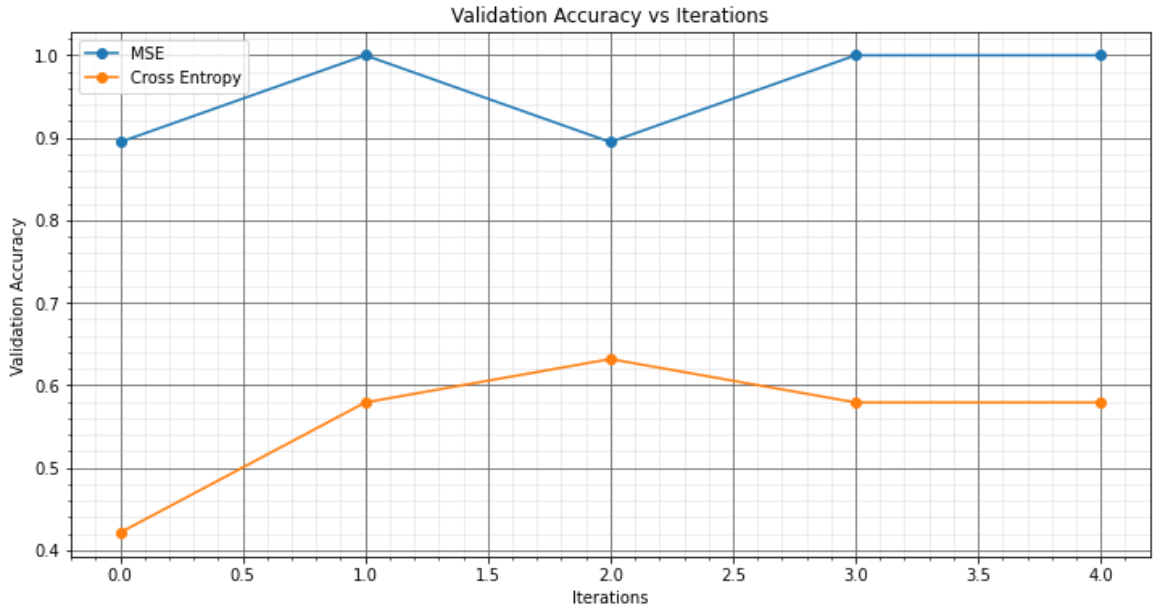
```
Epoch [ 1 / 5 ] : completed.
Epoch [ 2 / 5 ] : completed.
Epoch [ 3 / 5 ] : completed.
Epoch [ 4 / 5 ] : completed.
Epoch [ 5 / 5 ] : completed.
```

In [51]:

```
plt_1 = plt.figure(figsize=(12, 6))
plt.figure(1)
xtrainloss=np.arange(len(train_loss_5_mse))
plt.plot(xtrainloss,train_loss_5_mse,label="MSE")
plt.plot(xtrainloss,train_loss_5_ce,label="Cross Entropy")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Training Loss')
plt.title('Training Loss vs Iterations')
plt.legend()

plt_1 = plt.figure(figsize=(12, 6))
plt.figure(2)
xtestloss=np.arange(len(val_loss_5_mse))
plt.plot(xtestloss,val_loss_5_mse,label="MSE",marker='o')
plt.plot(xtestloss,val_loss_5_ce,label="Cross Entropy",marker='o')
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Validation Loss')
plt.title('Validation Loss vs Iterations')
plt.legend()

plt_1 = plt.figure(figsize=(12, 6))
plt.figure(3)
xbittrain=np.arange(len(val_acc_5_mse))
plt.plot(xbittrain,val_acc_5_mse,label="MSE",marker='o')
plt.plot(xbittrain,val_acc_5_ce,label="Cross Entropy",marker='o')
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Validation Accuracy')
plt.title('Validation Accuracy vs Iterations')
plt.legend()


plt.show()
```


Training Loss vs Iterations
MSE
Cross Entropy
Training Loss
Iterations
0
5
10
15
20
25
30
35
40
0
200
400
600
800
1000
1200


Validation Loss vs Iterations
MSE
Cross Entropy
Validation Loss
Iterations
0
2
4
6
8
10
12
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0



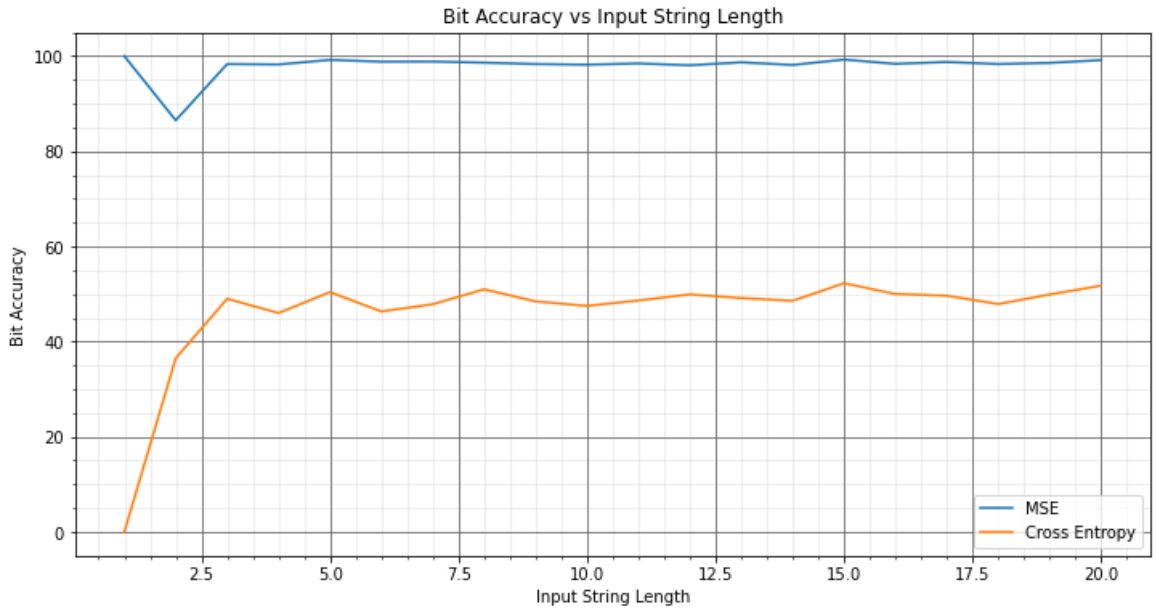
In [52]:

```
model5_5_mse.eval()
correctarr1 = np.zeros(20)
correctarr2 = np.zeros(20)
with torch.no_grad():
    for i in range(len(test_X)):
      a=torch.zeros((1,test_X[i].shape[0],test_X[i].shape[1]))
      a[0]=torch.from_numpy(test_X[i])
      output=model5_5_mse(a.float())
      label=torch.tensor(np.transpose(test_Y[i]))
      predicted=torch.zeros(output.shape)
      predicted[output>=0.5]=1
      predicted[output<0.5]=0
      correctarr1[len(label)-1] += (predicted == label.float()).sum().item()/(le
n(label))


    print('Accuracy with MSE:',(np.sum(correctarr1)/20))

model5_5_ce.eval()
with torch.no_grad():
    for i in range(len(test_X)):
      a=torch.zeros((1,test_X[i].shape[0],test_X[i].shape[1]))
      a[0]=torch.from_numpy(test_X[i])
      output=model5_5_ce(a.float())
      label=torch.tensor(np.transpose(test_Y[i]))
      predicted=torch.zeros(output.shape)
      predicted[output>0.5]=1
      predicted[output<=0.5]=0
      correctarr2[len(label)-1] += (predicted == label.float()).sum().item()/(le
n(label))
    print('Accuracy with Cross Entropy:',(np.sum(correctarr2)/20))
```

```
Accuracy with MSE: 98.04869198654802
Accuracy with Cross Entropy: 46.0380288442208
```

In [61]:

```
x=np.arange(1,21)
plt_1 = plt.figure(figsize=(12, 6))
plt.figure(1)
plt.plot(x,correctarr1,label="MSE")
plt.plot(x,correctarr2,label="Cross Entropy")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Input String Length')
plt.ylabel('Bit Accuracy')
plt.title('Bit Accuracy vs Input String Length')
plt.legend()
plt.show()
```



In [54]:

```
train_X_3=[]
train_Y_3=[]
for i in range(250):
  a,b=bin_generator(3)
  train_X_3.append(a)
  train_Y_3.append(b)

train_X_5=[]
train_Y_5=[]
for i in range(250):
  a,b=bin_generator(5)
  train_X_5.append(a)
  train_Y_5.append(b)

train_X_10=[]
train_Y_10=[]
for i in range(250):
  a,b=bin_generator(10)
  train_X_10.append(a)
  train_Y_10.append(b)
```

In [55]:

```
learning_rate = 0.01
epochs = 5
criterion5 = nn.MSELoss()
model55=LSTM_Q3(5)
optimizer55 = torch.optim.Adam(model55.parameters(), lr=learning_rate)
model56=LSTM_Q3(5)
optimizer56 = torch.optim.Adam(model56.parameters(), lr=learning_rate)
model57=LSTM_Q3(5)
optimizer57 = torch.optim.Adam(model57.parameters(), lr=learning_rate)
```

In [57]:

```
train_loss_3=[]
val_loss_3=[]
val_acc_3=[]
for epoch in range(epochs):
  for i in range(len(train_X_3)):
    a=torch.zeros((1,train_X_3[i].shape[0],train_X_3[i].shape[1]))
    a[0]=torch.from_numpy(train_X_3[i])
    output=model55(a.float())
    label=torch.tensor(np.transpose(train_Y_3[i]))
    loss = criterion5(output,label.float())
    train_loss_3.append(loss.item())

    optimizer55.zero_grad()
    loss.backward()
    optimizer55.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(val_X)):
    correct=0
    a=torch.zeros((1,val_X[i].shape[0],val_X[i].shape[1]))
    a[0]=torch.from_numpy(val_X[i])
    output=model55(a.float())
    label=torch.tensor(np.transpose(val_Y[i]))
    loss = criterion5(output,label.float())
    iteration+=1
    tempvalloss+=loss.item()

    predicted=torch.zeros(output.shape)
    predicted[output>=0.5]=1
    predicted[output<0.5]=0
    correct += (predicted == label.float()).sum().item()/len(label)

  val_acc_3.append(100*correct/iteration)
  val_loss_3.append(tempvalloss/iteration)
  print('Epoch [',epoch+1,'/',epochs,'] : completed.')
```

```
Epoch [ 1 / 5 ] : completed.
Epoch [ 2 / 5 ] : completed.
Epoch [ 3 / 5 ] : completed.
Epoch [ 4 / 5 ] : completed.
Epoch [ 5 / 5 ] : completed.
```

In [58]:

```
train_loss_5=[]
val_loss_5=[]
val_acc_5=[]
for epoch in range(epochs):
  for i in range(int(len(train_X_5))):
    a=torch.zeros((1,train_X_5[i].shape[0],train_X_5[i].shape[1]))
    a[0]=torch.from_numpy(train_X_5[i])
    output=model56(a.float())
    label=torch.tensor(np.transpose(train_Y_5[i]))
    loss = criterion5(output,label.float())
    train_loss_5.append(loss.item())

    optimizer56.zero_grad()
    loss.backward()
    optimizer56.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(val_X)):
    correct=0
    a=torch.zeros((1,val_X[i].shape[0],val_X[i].shape[1]))
    a[0]=torch.from_numpy(val_X[i])
    output=model56(a.float())
    label=torch.tensor(np.transpose(val_Y[i]))
    loss = criterion5(output,label.float())
    iteration+=1
    tempvalloss+=loss.item()

    predicted=torch.zeros(output.shape)
    predicted[output>=0.5]=1
    predicted[output<0.5]=0
    correct += (predicted == label.float()).sum().item()/len(label)

  val_acc_5.append(100*correct/iteration)
  val_loss_5.append(tempvalloss/iteration)
  print('Epoch [',epoch+1,'/',epochs,'] : completed.')
```

```
Epoch [ 1 / 5 ] : completed.
Epoch [ 2 / 5 ] : completed.
Epoch [ 3 / 5 ] : completed.
Epoch [ 4 / 5 ] : completed.
Epoch [ 5 / 5 ] : completed.
```

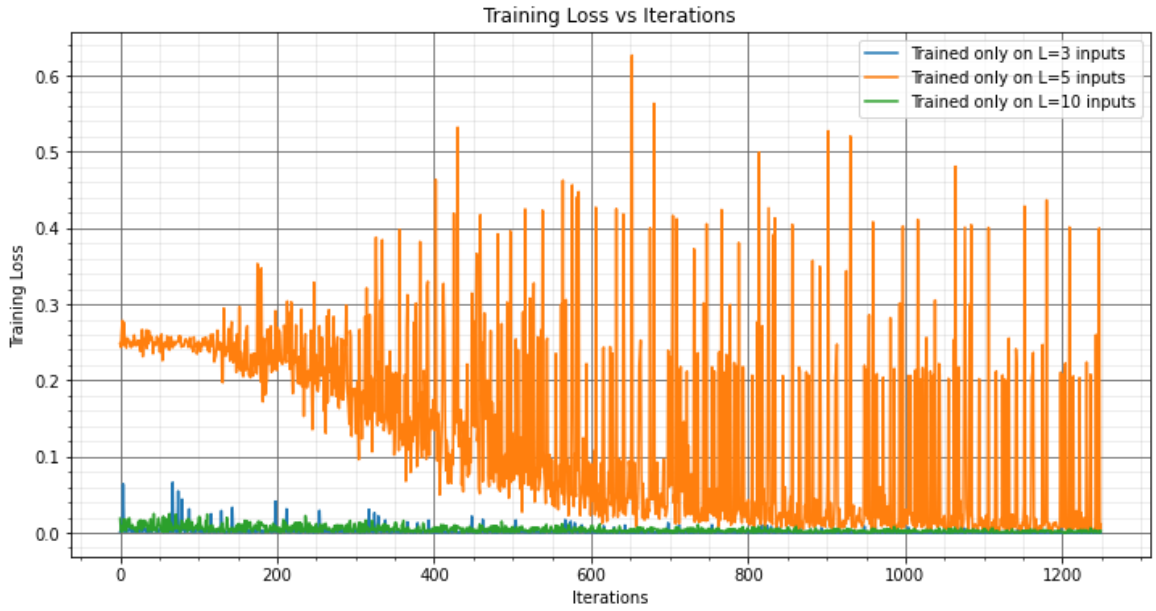
In [60]:

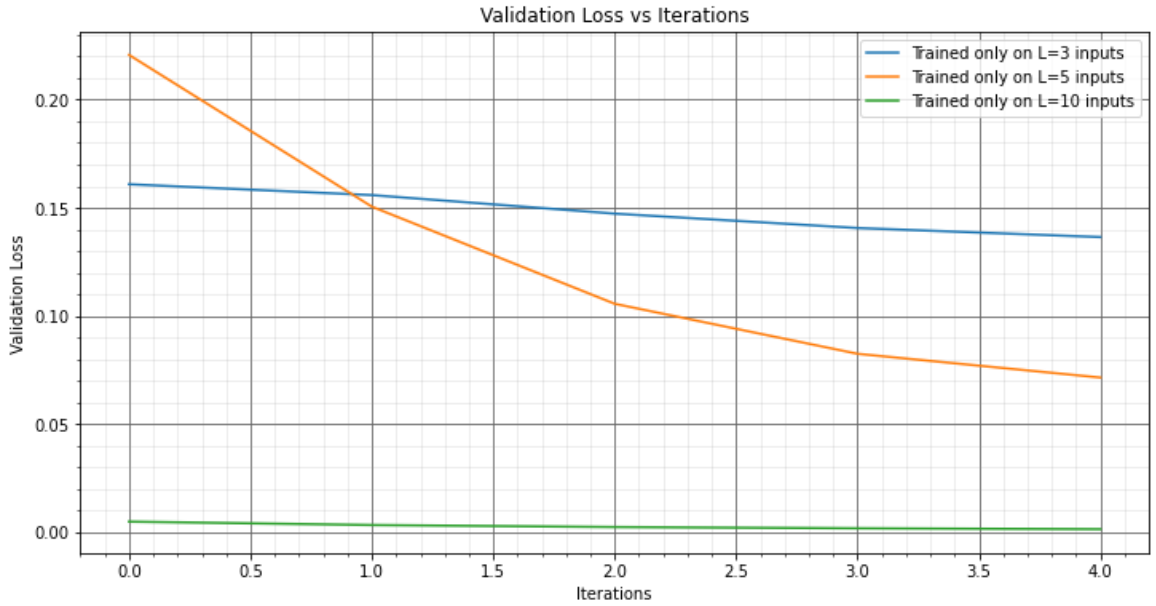
```
train_loss_10=[]
val_loss_10=[]
val_acc_10=[]
for epoch in range(epochs):
  for i in range(int(len(train_X_10))):
    a=torch.zeros((1,train_X_10[i].shape[0],train_X_10[i].shape[1]))
    a[0]=torch.from_numpy(train_X_10[i])
    output=model57(a.float())
    label=torch.tensor(np.transpose(train_Y_10[i]))
    loss = criterion5(output,label.float())
    train_loss_10.append(loss.item())

    optimizer57.zero_grad()
    loss.backward()
    optimizer57.step()

  iteration=0
  tempvalloss=0
  correctval=0

  for i in range(len(val_X)):
    correct=0
    a=torch.zeros((1,val_X[i].shape[0],val_X[i].shape[1]))
    a[0]=torch.from_numpy(val_X[i])
    output=model57(a.float())
    label=torch.tensor(np.transpose(val_Y[i]))
    loss = criterion5(output,label.float())
    iteration+=1
    tempvalloss+=loss.item()

    predicted=torch.zeros(output.shape)
    predicted[output>=0.5]=1
    predicted[output<0.5]=0
    correct += (predicted == label.float()).sum().item()/len(label)

  val_acc_10.append(100*correct/iteration)
  val_loss_10.append(tempvalloss/iteration)
  print('Epoch [',epoch+1,'/',epochs,'] : completed.')
```

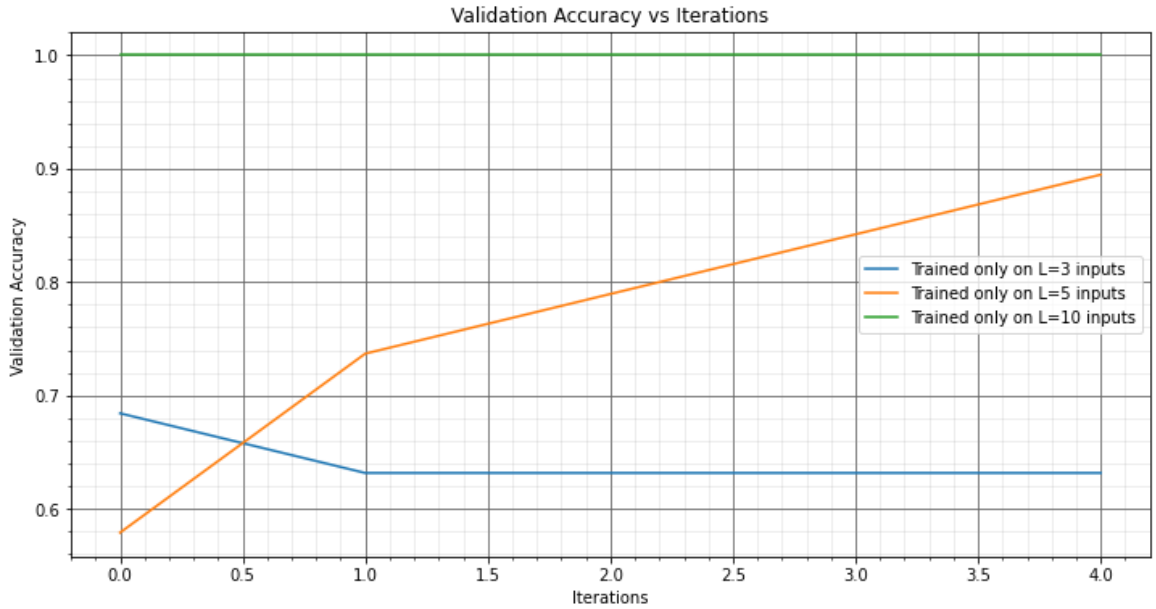
```
Epoch [ 1 / 5 ] : completed.
Epoch [ 2 / 5 ] : completed.
Epoch [ 3 / 5 ] : completed.
Epoch [ 4 / 5 ] : completed.
Epoch [ 5 / 5 ] : completed.
```

In [63]:

```
plt_1 = plt.figure(figsize=(12, 6))
plt.figure(1)
xtrainloss=np.arange(len(train_loss_3))
plt.plot(xtrainloss,train_loss_3,label="Trained only on L=3 inputs")
plt.plot(xtrainloss,train_loss_5,label="Trained only on L=5 inputs")
plt.plot(xtrainloss,train_loss_10,label="Trained only on L=10 inputs")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Training Loss')
plt.title('Training Loss vs Iterations')
plt.legend()

plt_1 = plt.figure(figsize=(12, 6))
plt.figure(2)
xtestloss=np.arange(len(val_loss_3))
plt.plot(xtestloss,val_loss_3,label="Trained only on L=3 inputs")
plt.plot(xtestloss,val_loss_5,label="Trained only on L=5 inputs")
plt.plot(xtestloss,val_loss_10,label="Trained only on L=10 inputs")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Validation Loss')
plt.title('Validation Loss vs Iterations')
plt.legend()

plt_1 = plt.figure(figsize=(12, 6))
plt.figure(3)
xbittrain=np.arange(len(val_acc_3))
plt.plot(xbittrain,val_acc_3,label="Trained only on L=3 inputs")
plt.plot(xbittrain,val_acc_5,label="Trained only on L=5 inputs")
plt.plot(xbittrain,val_acc_10,label="Trained only on L=10 inputs")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Iterations')
plt.ylabel('Validation Accuracy')
plt.title('Validation Accuracy vs Iterations')
plt.legend()

plt.show()
```


Training Loss vs Iterations
Trained only on L=3 inputs
Trained only on L=5 inputs
Trained only on L=10 inputs
Training Loss
Iterations
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
200
400
600
800
1000
1200


Validation Loss vs Iterations
Trained only on L=3 inputs
Trained only on L=5 inputs
Trained only on L=10 inputs
Validation Loss
Iterations
0.00
0.05
0.10
0.15
0.20
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0


Validation Accuracy vs Iterations
Validation Accuracy
Iterations
Trained only on L=3 inputs
Trained only on L=5 inputs
Trained only on L=10 inputs
1.0
0.9
0.8
0.7
0.6
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

In [64]:

```
model55.eval()
correctarr1 = np.zeros(20)
correctarr2 = np.zeros(20)
correctarr3 = np.zeros(20)
with torch.no_grad():
    for i in range(len(test_X)):
      a=torch.zeros((1,test_X[i].shape[0],test_X[i].shape[1]))
      a[0]=torch.from_numpy(test_X[i])
      output=model55(a.float())
      label=torch.tensor(np.transpose(test_Y[i]))
      predicted=torch.zeros(output.shape)
      predicted[output>=0.5]=1
      predicted[output<0.5]=0
      correctarr1[len(label)-1] += (predicted == label.float()).sum().item()/(le
n(label))


    print('Accuracy when trained on L=3 inputs:',(np.sum(correctarr1)/20))

model56.eval()
with torch.no_grad():
    for i in range(len(test_X)):
      a=torch.zeros((1,test_X[i].shape[0],test_X[i].shape[1]))
      a[0]=torch.from_numpy(test_X[i])
      output=model56(a.float())
      label=torch.tensor(np.transpose(test_Y[i]))
      predicted=torch.zeros(output.shape)
      predicted[output>0.5]=1
      predicted[output<=0.5]=0
      correctarr2[len(label)-1] += (predicted == label.float()).sum().item()/(le
n(label))
    print('Accuracy when trained on L=5 inputs:',(np.sum(correctarr2)/20))

model57.eval()
with torch.no_grad():
    for i in range(len(test_X)):
      a=torch.zeros((1,test_X[i].shape[0],test_X[i].shape[1]))
      a[0]=torch.from_numpy(test_X[i])
      output=model57(a.float())
      label=torch.tensor(np.transpose(test_Y[i]))
      predicted=torch.zeros(output.shape)
      predicted[output>0.5]=1
      predicted[output<=0.5]=0
      correctarr3[len(label)-1] += (predicted == label.float()).sum().item()/(le
n(label))
    print('Accuracy when trained on L=10 inputs:',(np.sum(correctarr3)/20))
```

```
Accuracy when trained on L=3 inputs: 78.5151106225216
Accuracy when trained on L=5 inputs: 92.19544692901694
Accuracy when trained on L=10 inputs: 100.0
```

In [66]:

```
x=np.arange(1,21)
plt_1=plt.figure(figsize=(12,6))
plt.figure(1)
plt.plot(x,correctarr1,label="Trained only on L=3 inputs")
plt.plot(x,correctarr2,label="Trained only on L=3 inputs")
plt.plot(x,correctarr3,label="Trained only on L=10 inputs")
plt.grid(b=True, which='major', color='#666666', linestyle='-')
plt.minorticks_on()
plt.grid(b=True, which='minor', color='#999999', linestyle='-', alpha=0.2)
plt.xlabel('Input String Length')
plt.ylabel('Accuracy')
plt.title('Accuracy vs Input String Length')
plt.legend()
plt.show()
```