Import Libraries

In [2]:
```
import numpy as np
import pandas as pd

from sklearn.datasets import load_breast_cancer

from sklearn.model_selection import StratifiedKFold, cross_val_score, GridSearchCV
from sklearn.tree import DecisionTreeClassifier
from sklearn.neighbors import KNeighborsClassifier
from sklearn.linear_model import LogisticRegression
from sklearn.svm import SVC
from sklearn.preprocessing import StandardScaler
from sklearn.pipeline import Pipeline
from sklearn.metrics import auc, roc_curve, confusion_matrix, classification_report
from sklearn.model_selection import train_test_split
from sklearn.preprocessing import OrdinalEncoder, LabelEncoder
from sklearn.naive_bayes import GaussianNB
from sklearn.metrics import matthews_corrcoef, cohen_kappa_score
from sklearn.metrics import ConfusionMatrixDisplay

import seaborn as sns
import matplotlib.pyplot as plt
```

Read Data

In [4]:
```
column_names = ["buying", "maint", "doors", "persons", "lug_boot", "safety", "class

url = "https://archive.ics.uci.edu/ml/machine-learning-databases/car/car.data"
df = pd.read_csv(url, names=column_names)

df.head()
```

Out[4]:

	buying	maint	doors	persons	lug_boot	safety	class
0	vhigh	vhigh	2	2	small	low	unacc
1	vhigh	vhigh	2	2	small	med	unacc
2	vhigh	vhigh	2	2	small	high	unacc
3	vhigh	vhigh	2	2	med	low	unacc
4	vhigh	vhigh	2	2	med	med	unacc

In [5]:
```
df['class'].value_counts()
```

Out[5]:
```
class
unacc    1210
acc       384
good       69
vgood      65
Name: count, dtype: int64
```

Data Preprocessing

Label Encoding of categorical features as they are ordinal

In [7]:
```
print(df['buying'].unique())
print(df['maint'].unique())
print(df['doors'].unique())
print(df['persons'].unique())
print(df['lug_boot'].unique())
print(df['safety'].unique())
print(df['class'].unique())
```

```
['vhigh' 'high' 'med' 'low']
['vhigh' 'high' 'med' 'low']
['2' '3' '4' '5more']
['2' '4' 'more']
['small' 'med' 'big']
['low' 'med' 'high']
['unacc' 'acc' 'vgood' 'good']
```

In [8]:
```
ordinal_mapping = {
    "buying": ["low", "med", "high", "vhigh"],
    "maint": ["low", "med", "high", "vhigh"],
    "lug_boot": ["small", "med", "big"],
    "safety": ["low", "med", "high"],
    "doors": ["2", "3", "4", "5more"],
    "persons": ["2", "4", "more"]
}

encoder = OrdinalEncoder(categories=[ordinal_mapping[col] for col in ordinal_mappin
df_encoded = df.copy()
df_encoded[list(ordinal_mapping.keys())] = encoder.fit_transform(df[list(ordinal_ma

df_encoded[list(ordinal_mapping.keys())] = df_encoded[list(ordinal_mapping.keys())]

label_encoder = LabelEncoder()
df_encoded["class"] = label_encoder.fit_transform(df["class"])

encoded_mappings = {}

for col in ordinal_mapping:
    encoded_mappings[col] = {category: idx for idx, category in enumerate(ordinal_m

encoded_mappings["class"] = {category: idx for idx, category in enumerate(label_enc

for col, mapping in encoded_mappings.items():
    print(f"Encoding for {col}:")
```

```python
    for category, code in mapping.items():
        print(f"  {category} -> {code}")
    print("-" * 30)

print("\nEncoded DataFrame:")
print(df_encoded.head())
```

```
Encoding for buying:
  low -> 0
  med -> 1
  high -> 2
  vhigh -> 3
------------------------------
Encoding for maint:
  low -> 0
  med -> 1
  high -> 2
  vhigh -> 3
------------------------------
Encoding for lug_boot:
  small -> 0
  med -> 1
  big -> 2
------------------------------
Encoding for safety:
  low -> 0
  med -> 1
  high -> 2
------------------------------
Encoding for doors:
  2 -> 0
  3 -> 1
  4 -> 2
  5more -> 3
------------------------------
Encoding for persons:
  2 -> 0
  4 -> 1
  more -> 2
------------------------------
Encoding for class:
  acc -> 0
  good -> 1
  unacc -> 2
  vgood -> 3
------------------------------

Encoded DataFrame:
   buying  maint  doors  persons  lug_boot  safety  class
0       3      3      0        0         0       0      2
1       3      3      0        0         0       1      2
2       3      3      0        0         0       2      2
3       3      3      0        0         1       0      2
4       3      3      0        0         1       1      2
```

Train and Test Split

In [10]:
```
# Split data into train and test sets (80% train, 20% test)
X_train, X_test, y_train, y_test = train_test_split(df_encoded.drop('class', axis=1
```

Nested Cross-Validation Setup

In [12]:
```
outer_cv = StratifiedKFold(n_splits=5, shuffle=True, random_state=11)
inner_cv = StratifiedKFold(n_splits=5, shuffle=True, random_state=11)

param_grids = {
    "Decision_Tree": {"clf__max_depth": [3, 5, 10, None], "clf__min_samples_split":
    "KNN": {"clf__n_neighbors": [3, 5, 7, 9], "clf__weights": ['uniform', 'distance
    "Logistic_Regression": {"clf__C": [0.01, 0.1, 1, 10, 100], "clf__penalty": ['l1
    "SVM": {"clf__C": [0.1, 1, 10], "clf__kernel": ['linear', 'rbf', 'poly']}
}

models = {
    "Decision_Tree": DecisionTreeClassifier(random_state=42),
    "KNN": KNeighborsClassifier(),
    "Logistic_Regression": LogisticRegression(random_state=42),
    "Naive_Bayes": GaussianNB(),
    "SVM": SVC(probability=True, random_state=42)
}
```

Run Nested Cross-Validation for Each Model

In [14]:
```
results = {}

for model_name, model in models.items():
    print(f"Training {model_name}...")

    scores = {
        "accuracy": [],
        "precision": [],
        "recall": [],
        "f1_score": [],
        "mcc": [],
        "kappa": []
    }

    for train_idx, test_idx in outer_cv.split(X_train, y_train):
        X_train_cv, X_test_cv = X_train.iloc[train_idx], X_train.iloc[test_idx]
        y_train_cv, y_test_cv = y_train.iloc[train_idx], y_train.iloc[test_idx]

        scaler = StandardScaler()
        X_train_scaled = scaler.fit_transform(X_train_cv)
        X_test_scaled = scaler.transform(X_test_cv)

        pipeline = Pipeline([("clf", model)])
```

```
        if model_name in param_grids:
            grid_search = GridSearchCV(pipeline, param_grids[model_name], cv=inner_
            grid_search.fit(X_train_scaled, y_train_cv)
            best_model = grid_search.best_estimator_
        else:
            best_model = model
            best_model.fit(X_train_scaled, y_train_cv)

        y_pred = best_model.predict(X_test_scaled)

        scores["accuracy"].append(accuracy_score(y_test_cv, y_pred))
        scores["precision"].append(precision_score(y_test_cv, y_pred, average="weig
        scores["recall"].append(recall_score(y_test_cv, y_pred, average="weighted")
        scores["f1_score"].append(f1_score(y_test_cv, y_pred, average="weighted"))
        scores["mcc"].append(matthews_corrcoef(y_test_cv, y_pred))
        scores["kappa"].append(cohen_kappa_score(y_test_cv, y_pred))

    results[model_name] = {metric: np.mean(scores[metric]) for metric in scores}

results_df = pd.DataFrame.from_dict(results, orient="index")
results_df
```

```
Training Decision_Tree...
Training KNN...
Training Logistic_Regression...
Training Naive_Bayes...
Training SVM...
```

Out[14]:

	accuracy	precision	recall	f1_score	mcc	kappa
Decision_Tree	0.971765	0.973085	0.971765	0.971906	0.938977	0.938649
KNN	0.952245	0.953932	0.952245	0.951191	0.895843	0.895052
Logistic_Regression	0.808259	0.784231	0.808259	0.790172	0.546304	0.536355
Naive_Bayes	0.704018	0.780714	0.704018	0.706321	0.411884	0.390506
SVM	0.984079	0.984500	0.984079	0.984005	0.965553	0.965289

Final SVM Model Run

Hyperparameter Tuning, Training and Performance Metrics

In [16]:

```
scoring_metric = make_scorer(matthews_corrcoef)

param_grid = {
    'clf__C': [0.01, 0.1, 1, 10, 20, 50, 70, 100],
    'clf__kernel': ['linear', 'rbf', 'poly']
}

outer_cv = StratifiedKFold(n_splits=5, shuffle=True, random_state=20)
inner_cv = StratifiedKFold(n_splits=5, shuffle=True, random_state=20)
```

```python
best_params_list = []
nested_scores = []

for train_idx, test_idx in outer_cv.split(X_train, y_train):
    X_train_cv, X_test_cv = X_train.iloc[train_idx], X_train.iloc[test_idx]
    y_train_cv, y_test_cv = y_train.iloc[train_idx], y_train.iloc[test_idx]

    scaler = StandardScaler()
    X_train_scaled = scaler.fit_transform(X_train_cv)
    X_test_scaled = scaler.transform(X_test_cv)

    pipeline = Pipeline([
        ("clf", SVC(probability=True, random_state=20))
    ])

    grid_search = GridSearchCV(pipeline, param_grid, cv=inner_cv, scoring=scoring_m
    grid_search.fit(X_train_scaled, y_train_cv)

    best_model = grid_search.best_estimator_
    best_params_list.append(grid_search.best_params_)

    y_pred = best_model.predict(X_test_scaled)

    accuracy = accuracy_score(y_test_cv, y_pred)  # Use accuracy instead of recall
    nested_scores.append(accuracy)

best_params_final = pd.DataFrame(best_params_list).mode().iloc[0].to_dict()

final_model = SVC(C=best_params_final["clf__C"],
                  kernel=best_params_final["clf__kernel"],
                  probability=True,
                  decision_function_shape='ovr',
                  random_state=20)

scaler = StandardScaler()
X_train_scaled = scaler.fit_transform(X_train)
X_test_scaled = scaler.transform(X_test)

final_model.fit(X_train_scaled, y_train)

y_pred_final = final_model.predict(X_test_scaled)
y_pred_proba = final_model.predict_proba(X_test_scaled)[:, 1]

final_metrics = {
    "Accuracy": accuracy_score(y_test, y_pred_final),
    "Precision": precision_score(y_test, y_pred_final, average="weighted"),
    "Recall": recall_score(y_test, y_pred_final, average="weighted"),
    "F1-Score": f1_score(y_test, y_pred_final, average="weighted"),
    "MCC": matthews_corrcoef(y_test, y_pred_final),
    "Kappa": cohen_kappa_score(y_test, y_pred_final)
}

final_metrics_df = pd.DataFrame([final_metrics])
best_params_df = pd.DataFrame([best_params_final])

print("\nBest Hyperparameters for SVM:")
```

```
print(best_params_df)

print("\nFinal Model Performance Metrics:")
print(final_metrics_df)
```

```
Best Hyperparameters for SVM:
   clf__C clf__kernel
0      50         rbf

Final Model Performance Metrics:
   Accuracy  Precision    Recall  F1-Score      MCC     Kappa
0  0.988439   0.988468  0.988439  0.988332  0.97469  0.974512
```

Confusion Matrix

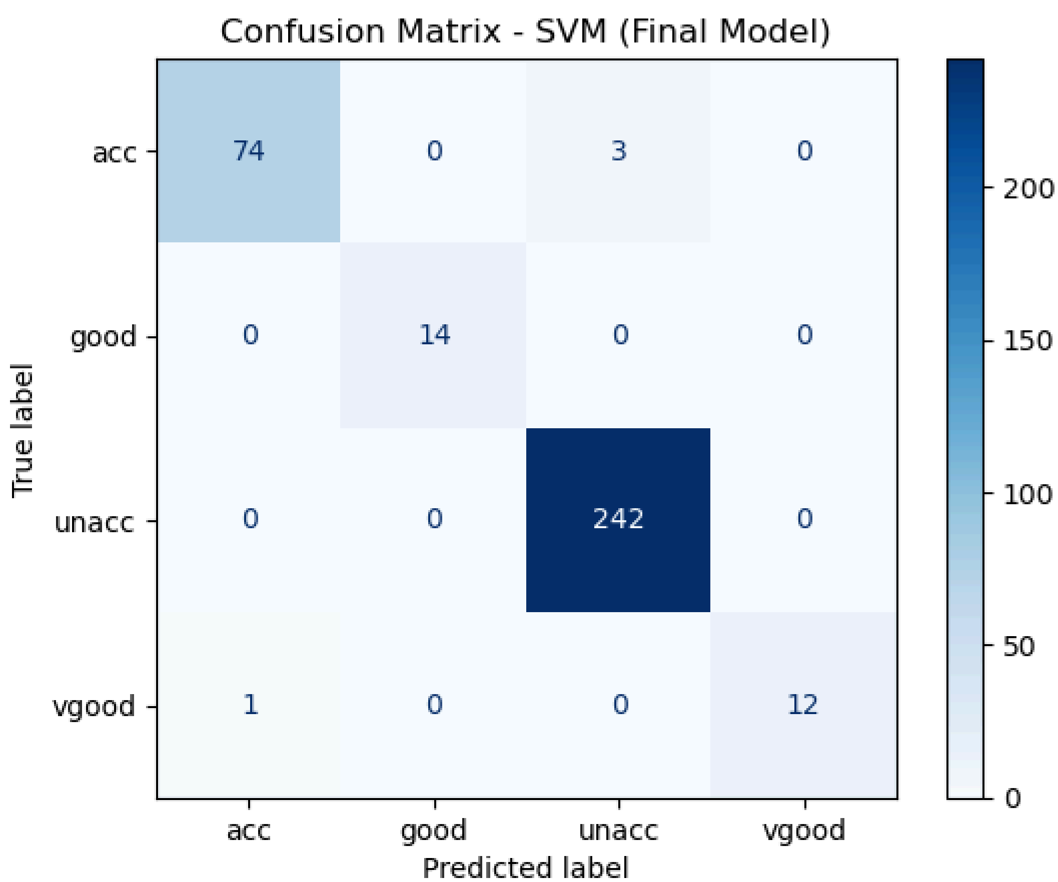
In [18]:

```
conf_matrix = confusion_matrix(y_test, y_pred_final)

class_labels = label_encoder.classes_  # Ensure this matches your encoded labels

plt.figure(figsize=(6, 5))
disp = ConfusionMatrixDisplay(confusion_matrix=conf_matrix, display_labels=class_la
disp.plot(cmap='Blues', values_format='d')
plt.title("Confusion Matrix - SVM (Final Model)")
plt.show()
```

```
<Figure size 600x500 with 0 Axes>
```



Per-Class Performance

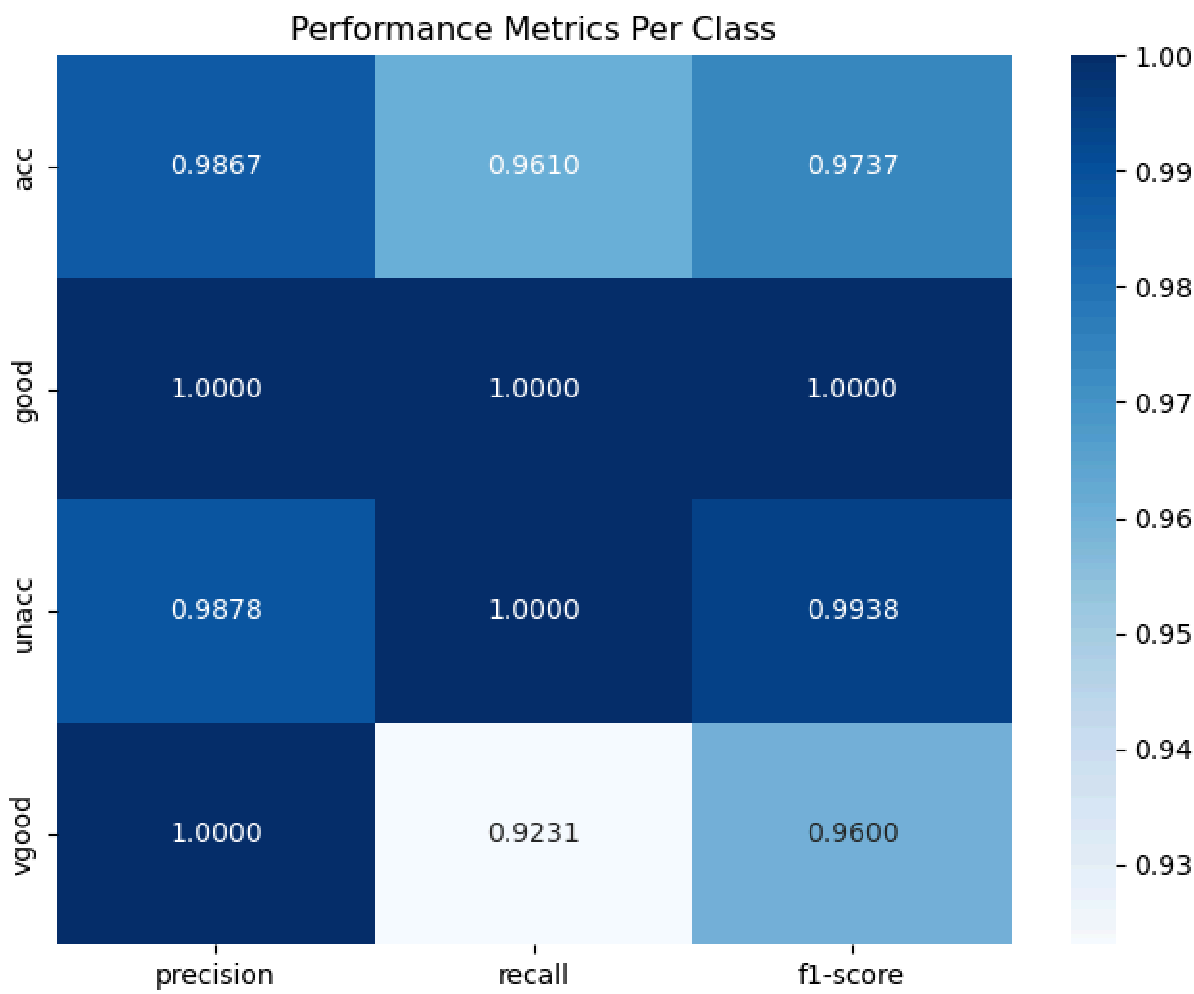
In [20]:
```
class_report = classification_report(y_test, y_pred_final, target_names=label_encod

final_metrics_per_class = pd.DataFrame(class_report).T

print("\nFinal Model Performance Metrics Per Class:")
print(final_metrics_per_class)

plt.figure(figsize=(8, 6))
sns.heatmap(final_metrics_per_class.iloc[:-3, :-1], annot=True, cmap="Blues", fmt="
plt.title("Performance Metrics Per Class")
plt.show()
```

```
Final Model Performance Metrics Per Class:
              precision    recall  f1-score     support
acc            0.986667  0.961039  0.973684   77.000000
good           1.000000  1.000000  1.000000   14.000000
unacc          0.987755  1.000000  0.993840  242.000000
vgood          1.000000  0.923077  0.960000   13.000000
accuracy       0.988439  0.988439  0.988439    0.988439
macro avg      0.993605  0.971029  0.981881  346.000000
weighted avg   0.988468  0.988439  0.988332  346.000000
```



In [ ]:

```

```