**Roll No: 1703016**

**Lab Final**

**Lab Task Q1**

**Question: Show an OpenGL program which will show:**

**a) Hello Triangle/Shapes: Two 2D Rectangle.**

**b) Shader/Texture: Mix of 2 different Textures for each.**

**c) Transformations and Coordinate System: Their location will change using keyboard.**

**Solution (Bold your own written code):**

**main.cpp**

```
// Roll: 1703016

#include "glad.h"
#include "glfw3.h"

#define STB_IMAGE_IMPLEMENTATION
#include "stb_image.h"

// #include "learnopengl/filesystem.h"
// #include "learnopengl/shader_s.h"

#include "glm/glm.hpp"
#include "glm/gtc/matrix_transform.hpp"

#include <sstream>
#include <fstream>
#include <iostream>

void framebuffer_size_callback(GLFWwindow* window, int
width, int height);
void processInput(GLFWwindow *window);

// settings
const unsigned int SCR_WIDTH = 800;
const unsigned int SCR_HEIGHT = 600;

int main()
{
    // glfw: initialize and configure
    // ------------------------------
```

```
    glfwInit();
    glfwWindowHint(GLFW_CONTEXT_VERSION_MAJOR, 3);
    glfwWindowHint(GLFW_CONTEXT_VERSION_MINOR, 3);
    glfwWindowHint(GLFW_OPENGL_PROFILE,
GLFW_OPENGL_CORE_PROFILE);

#ifdef __APPLE__
    glfwWindowHint(GLFW_OPENGL_FORWARD_COMPAT, GL_TRUE);
#endif

    // glfw window creation
    // --------------------
    GLFWwindow* window = glfwCreateWindow(SCR_WIDTH,
SCR_HEIGHT, "LearnOpenGL", NULL, NULL);
    if (window == NULL)
    {
        std::cout << "Failed to create GLFW window" <<
std::endl;
        glfwTerminate();
        return -1;
    }
    glfwMakeContextCurrent(window);
    glfwSetFramebufferSizeCallback(window,
framebuffer_size_callback);

    // glad: load all OpenGL function pointers
    // ---------------------------------------
    if
(!gladLoadGLLoader((GLADloadproc)glfwGetProcAddress))
    {
        std::cout << "Failed to initialize GLAD" <<
std::endl;
        return -1;
    }

    // configure global opengl state
    // -----------------------------
    glEnable(GL_DEPTH_TEST);

    // build and compile our shader zprogram
    // ------------------------------------
    // Shader ourShader("src/shader/4.1.texture.vs",
"src/shader/4.1.texture.fs");
    const char* vertexPath = "src/shader/template1.vs";
    const char* fragmentPath =
"src/shader/template1.fs";
```

```
    std::string vertexCode;
    std::string fragmentCode;
    std::ifstream vShaderFile;
    std::ifstream fShaderFile;
    // open files
    vShaderFile.open(vertexPath);
    fShaderFile.open(fragmentPath);
    std::stringstream vShaderStream, fShaderStream;
    // read file's buffer contents into streams
    vShaderStream << vShaderFile.rdbuf();
    fShaderStream << fShaderFile.rdbuf();
    // close file handlers
    vShaderFile.close();
    fShaderFile.close();
    // convert stream into string
    vertexCode = vShaderStream.str();
    fragmentCode = fShaderStream.str();
    const char* vShaderCode = vertexCode.c_str();
    const char * fShaderCode = fragmentCode.c_str();


    // build and compile our shader program
    // ------------------------------------
    // vertex shader
    unsigned int vertexShader =
glCreateShader(GL_VERTEX_SHADER);
    glShaderSource(vertexShader, 1, &vShaderCode, NULL);
    glCompileShader(vertexShader);
    // check for shader compile errors
    int success;
    char infoLog[512];
    glGetShaderiv(vertexShader, GL_COMPILE_STATUS,
&success);
    if (!success)
    {
        glGetShaderInfoLog(vertexShader, 512, NULL,
infoLog);
        std::cout <<
"ERROR::SHADER::VERTEX::COMPILATION_FAILED\n" << infoLog
<< std::endl;
    }
    // fragment shader
    unsigned int fragmentShader =
glCreateShader(GL_FRAGMENT_SHADER);
    glShaderSource(fragmentShader, 1, &fShaderCode,
```

```
NULL);
    glCompileShader(fragmentShader);
    // check for shader compile errors
    glGetShaderiv(fragmentShader, GL_COMPILE_STATUS,
&success);
    if (!success)
    {
        glGetShaderInfoLog(fragmentShader, 512, NULL,
infoLog);
        std::cout <<
"ERROR::SHADER::FRAGMENT::COMPILATION_FAILED\n" <<
infoLog << std::endl;
    }
    // link shaders
    unsigned int shaderProgram = glCreateProgram();
    glAttachShader(shaderProgram, vertexShader);
    glAttachShader(shaderProgram, fragmentShader);
    glLinkProgram(shaderProgram);
    // check for linking errors
    glGetProgramiv(shaderProgram, GL_LINK_STATUS,
&success);
    if (!success) {
        glGetProgramInfoLog(shaderProgram, 512, NULL,
infoLog);
        std::cout <<
"ERROR::SHADER::PROGRAM::LINKING_FAILED\n" << infoLog <<
std::endl;
    }
    glDeleteShader(vertexShader);
    glDeleteShader(fragmentShader);

    // set up vertex data (and buffer(s)) and configure
vertex attributes
    // ------------------------------------------------
-----------------
    float vertices[] = {
        -0.5f, -0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
0.0f,
         0.5f, -0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
0.0f,
         0.5f,  0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
1.0f,
         0.5f,  0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
1.0f,
        -0.5f,  0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
1.0f,
```

```
        -0.5f, -0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
0.0f,

        -0.5f, -0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
0.0f,
         0.5f, -0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
0.0f,
         0.5f,  0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
1.0f,
         0.5f,  0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
1.0f,
        -0.5f,  0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
1.0f,
        -0.5f, -0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
0.0f,

        -0.5f,  0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
0.0f,
        -0.5f,  0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
1.0f,
        -0.5f, -0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
1.0f,
        -0.5f, -0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
1.0f,
        -0.5f, -0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
0.0f,
        -0.5f,  0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
0.0f,

         0.5f,  0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
0.0f,
         0.5f,  0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
1.0f,
         0.5f, -0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
1.0f,
         0.5f, -0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
1.0f,
         0.5f, -0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
0.0f,
         0.5f,  0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
0.0f,

        -0.5f, -0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
1.0f,
         0.5f, -0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
1.0f,
```

```
         0.5f, -0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
0.0f,
         0.5f, -0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
0.0f,
        -0.5f, -0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
0.0f,
        -0.5f, -0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
1.0f,

        -0.5f,  0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
1.0f,
         0.5f,  0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
1.0f,
         0.5f,  0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
0.0f,
         0.5f,  0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   1.0f,
0.0f,
        -0.5f,  0.5f,  0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
0.0f,
        -0.5f,  0.5f, -0.5f,  1.0f, 0.0f, 0.0f,   0.0f,
1.0f
    };

    // world space positions of our cubes
    glm::vec3 cubePositions[] = {
        glm::vec3( 0.0f,  0.0f,  0.0f),
        glm::vec3( 2.0f,  5.0f, -15.0f),
        glm::vec3(-1.5f, -2.2f, -2.5f)
    };

    unsigned int VBO, VAO;
    glGenVertexArrays(1, &VAO);
    glGenBuffers(1, &VBO);

    glBindVertexArray(VAO);

    glBindBuffer(GL_ARRAY_BUFFER, VBO);
    glBufferData(GL_ARRAY_BUFFER, sizeof(vertices),
vertices, GL_STATIC_DRAW);

    // position attribute
    glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 8 *
sizeof(float), (void*)0);
    glEnableVertexAttribArray(0);
    // color attribute
    glVertexAttribPointer(1, 3, GL_FLOAT, GL_FALSE, 8 *
```

```
sizeof(float), (void*)(3 * sizeof(float)));
    glEnableVertexAttribArray(1);
    // texture coord attribute
    glVertexAttribPointer(2, 2, GL_FLOAT, GL_FALSE, 8 *
sizeof(float), (void*)(6 * sizeof(float)));
    glEnableVertexAttribArray(2);

    // load and create a texture
    // -------------------------
    unsigned int texture1, texture2;
    // texture 1
    // ---------
    glGenTextures(1, &texture1);
    glBindTexture(GL_TEXTURE_2D, texture1);
    // set the texture wrapping parameters
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S,
GL_REPEAT);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T,
GL_REPEAT);
    // set texture filtering parameters
    glTexParameteri(GL_TEXTURE_2D,
GL_TEXTURE_MIN_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_2D,
GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    // load image, create texture and generate mipmaps
    int width, height, nrChannels;
    stbi_set_flip_vertically_on_load(true); // tell
stb_image.h to flip loaded texture's on the y-axis.
    unsigned char *data =
stbi_load("resources/textures/container.jpg", &width,
&height, &nrChannels, 0);
    if (data)
    {
        glTexImage2D(GL_TEXTURE_2D, 0, GL_RGB, width,
height, 0, GL_RGB, GL_UNSIGNED_BYTE, data);
        glGenerateMipmap(GL_TEXTURE_2D);
    }
    else
    {
        std::cout << "Failed to load texture" <<
std::endl;
    }
    stbi_image_free(data);
    // texture 2
    // ---------
    glGenTextures(1, &texture2);
```

```
    glBindTexture(GL_TEXTURE_2D, texture2);
    // set the texture wrapping parameters
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S,
GL_REPEAT);
    glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T,
GL_REPEAT);
    // set texture filtering parameters
    glTexParameteri(GL_TEXTURE_2D,
GL_TEXTURE_MIN_FILTER, GL_LINEAR);
    glTexParameteri(GL_TEXTURE_2D,
GL_TEXTURE_MAG_FILTER, GL_LINEAR);
    // load image, create texture and generate mipmaps
    data =
stbi_load("resources/textures/awesomeface.png", &width,
&height, &nrChannels, 0);
    if (data)
    {
        // note that the awesomeface.png has
transparency and thus an alpha channel, so make sure to
tell OpenGL the data type is of GL_RGBA
        glTexImage2D(GL_TEXTURE_2D, 0, GL_RGB, width,
height, 0, GL_RGBA, GL_UNSIGNED_BYTE, data);
        glGenerateMipmap(GL_TEXTURE_2D);
    }
    else
    {
        std::cout << "Failed to load texture" <<
std::endl;
    }
    stbi_image_free(data);

    glUseProgram(shaderProgram);
    glUniform1i(glGetUniformLocation(shaderProgram,
"texture1"), 0);
    glUniform1i(glGetUniformLocation(shaderProgram,
"texture2"), 1);

    // render loop
    // -----------
    while (!glfwWindowShouldClose(window))
    {
        // input
        // -----
        processInput(window);

        // render
```

```
        // ------
        glClearColor(0.2f, 0.3f, 0.3f, 1.0f);
        glClear(GL_COLOR_BUFFER_BIT |
GL_DEPTH_BUFFER_BIT); // also clear the depth buffer
now!

        // bind textures on corresponding texture units
        glActiveTexture(GL_TEXTURE0);
        glBindTexture(GL_TEXTURE_2D, texture1);
        glActiveTexture(GL_TEXTURE1);
        glBindTexture(GL_TEXTURE_2D, texture2);

        // activate shader
        glUseProgram(shaderProgram);

        // create transformations
        glm::mat4 view          = glm::mat4(1.0f);
        glm::mat4 projection    = glm::mat4(1.0f);
        view  = glm::translate(view, glm::vec3(0.0f,
0.0f, -3.0f));
        projection =
glm::perspective(glm::radians(45.0f), (float)SCR_WIDTH /
(float)SCR_HEIGHT, 0.1f, 100.0f);

glUniformMatrix4fv(glGetUniformLocation(shaderProgram,
"view"      ), 1, GL_FALSE, &view[0][0]);

glUniformMatrix4fv(glGetUniformLocation(shaderProgram,
"projection"), 1, GL_FALSE, &projection[0][0]);

        // render container
        glBindVertexArray(VAO);


        unsigned int number_of_cube = 2;
        for (unsigned int i = 0; i < number_of_cube;
i++)
        {
            // calculate the model matrix for each
object and pass it to shader before drawing
            glm::mat4 model = glm::mat4(1.0f);
            model = glm::scale(model, glm::vec3(1.0f));
            model = glm::translate(model,
cubePositions[i]);
            float angle = 20.0f * (0);
            model = glm::rotate(model,
```

```
glm::radians(angle), glm::vec3(1.0f, 0.3f, 0.5f));

glUniformMatrix4fv(glGetUniformLocation(shaderProgram,
"model"), 1, GL_FALSE, &model[0][0]);
            glDrawArrays(GL_TRIANGLES, 0, 36);
        }

        // glfw: swap buffers and poll IO events (keys
pressed/released, mouse moved etc.)
        // -------------------------------------------
-------------------------------
        glfwSwapBuffers(window);
        glfwPollEvents();
    }

    // optional: de-allocate all resources once they've
outlived their purpose:
    // ------------------------------------------------
-----------------------
    glDeleteVertexArrays(1, &VAO);
    glDeleteBuffers(1, &VBO);

    // glfw: terminate, clearing all previously
allocated GLFW resources.
    // ------------------------------------------------
-----------------
    glfwTerminate();
    return 0;
}

// process all input: query GLFW whether relevant keys
are pressed/released this frame and react accordingly
// ---------------------------------------------------
-------------------------------------------------
void processInput(GLFWwindow *window)
{
    //Keyboard Example, F KEY = GLFW_KEY_F
    //Keyboard Example, 1 KEY = GLFW_KEY_1
    if (glfwGetKey(window, GLFW_KEY_ESCAPE) ==
GLFW_PRESS)
        glfwSetWindowShouldClose(window, true);

    if (glfwGetKey(window, GLFW_KEY_K) == GLFW_PRESS) {

        glm::vec3 cubePosition[] = {
            glm::vec3( 0.0f,  5.0f,  0.0f),
```

```
            glm::vec3( 2.0f,  8.0f, -15.0f),
            glm::vec3(-1.5f, -5.2f, -2.5f)
        };



        unsigned int number_of_cube = 2;
        for (unsigned int i = 0; i < number_of_cube;
i++)
        {
            // calculate the model matrix for each
object and pass it to shader before drawing
            glm::mat4 model = glm::mat4(1.0f);
            model = glm::scale(model, glm::vec3(1.0f));
            model = glm::translate(model,
cubePosition[i]);
            // float angle = 20.0f * (0);
            // model = glm::rotate(model,
glm::radians(angle), glm::vec3(1.0f, 0.3f, 0.5f));
            //
glUniformMatrix4fv(glGetUniformLocation(shaderProgram,
"model"), 1, GL_FALSE, &model[0][0]);
            glDrawArrays(GL_TRIANGLES, 0, 36);
        }
    }
}

// glfw: whenever the window size changed (by OS or user
resize) this callback function executes
// ---------------------------------------------------
---------------------------------------
void framebuffer_size_callback(GLFWwindow* window, int
width, int height)
{
    // make sure the viewport matches the new window
dimensions; note that width and
    // height will be significantly larger than
specified on retina displays.
    glViewport(0, 0, width, height);
}
```

**vertex shader**

```
#version 330 core
layout (location = 0) in vec3 aPos;
layout (location = 1) in vec3 aColor;
```

```
layout (location = 2) in vec2 aTexCoord;

out vec3 ourColor;
out vec2 TexCoord;

uniform mat4 model;
uniform mat4 view;
uniform mat4 projection;

void main()
{
    gl_Position = projection * view * model * vec4(aPos,
1.0f);
     ourColor = aColor;
     TexCoord = vec2(aTexCoord.x, aTexCoord.y);
}
```

**fragment shader [Q1(a)]**

```
#version 330 core
out vec4 FragColor;

in vec3 ourColor;
in vec2 TexCoord;

// texture samplers
uniform sampler2D texture1;
uniform sampler2D texture2;

void main()
{
    FragColor = vec4(0.5f, 0.5f, 0.5f, 1.0f);
}
```

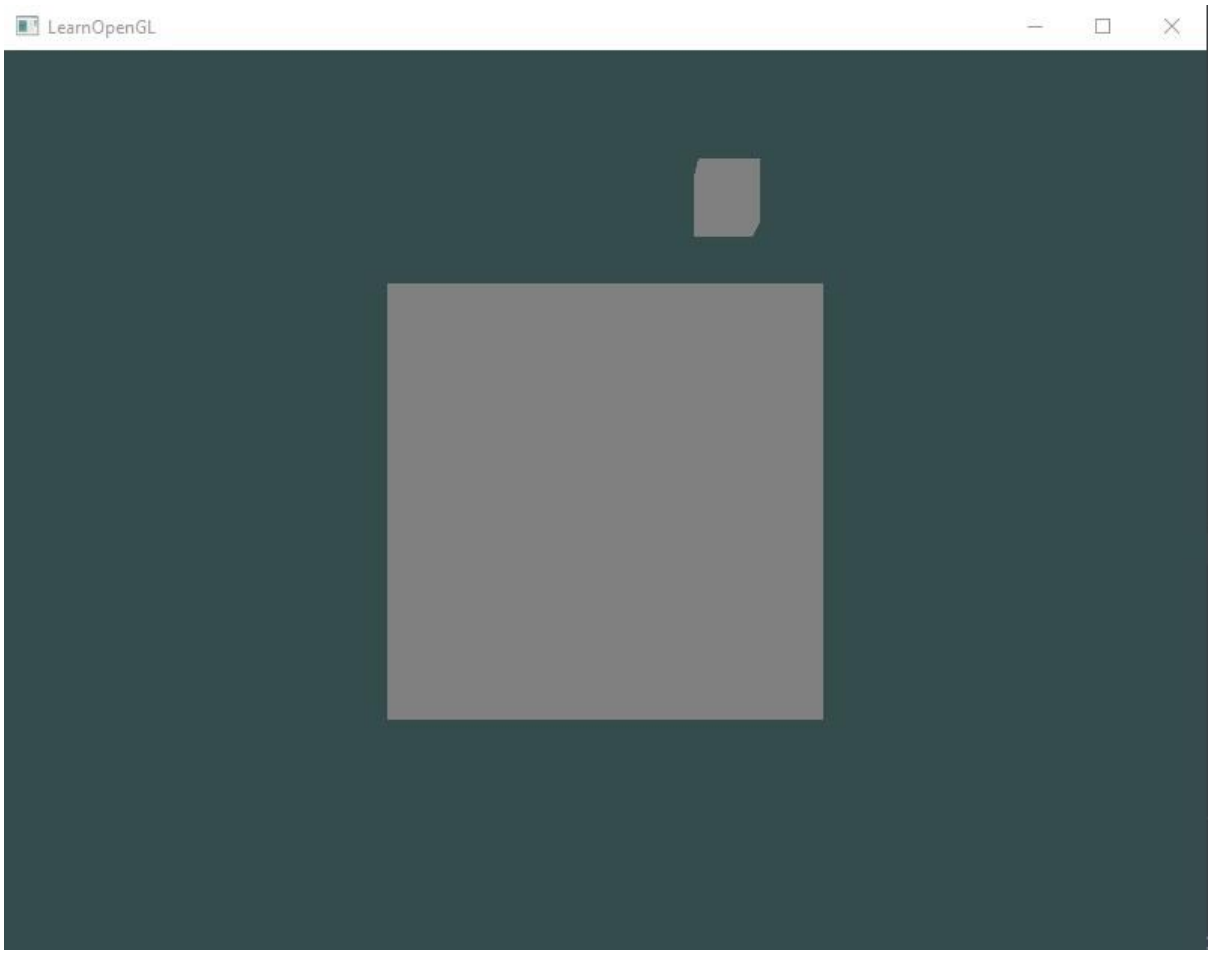
**fragment shader [Q1(b)]**

```
#version 330 core
out vec4 FragColor;

in vec3 ourColor;
in vec2 TexCoord;

// texture samplers
uniform sampler2D texture1;
uniform sampler2D texture2;
```

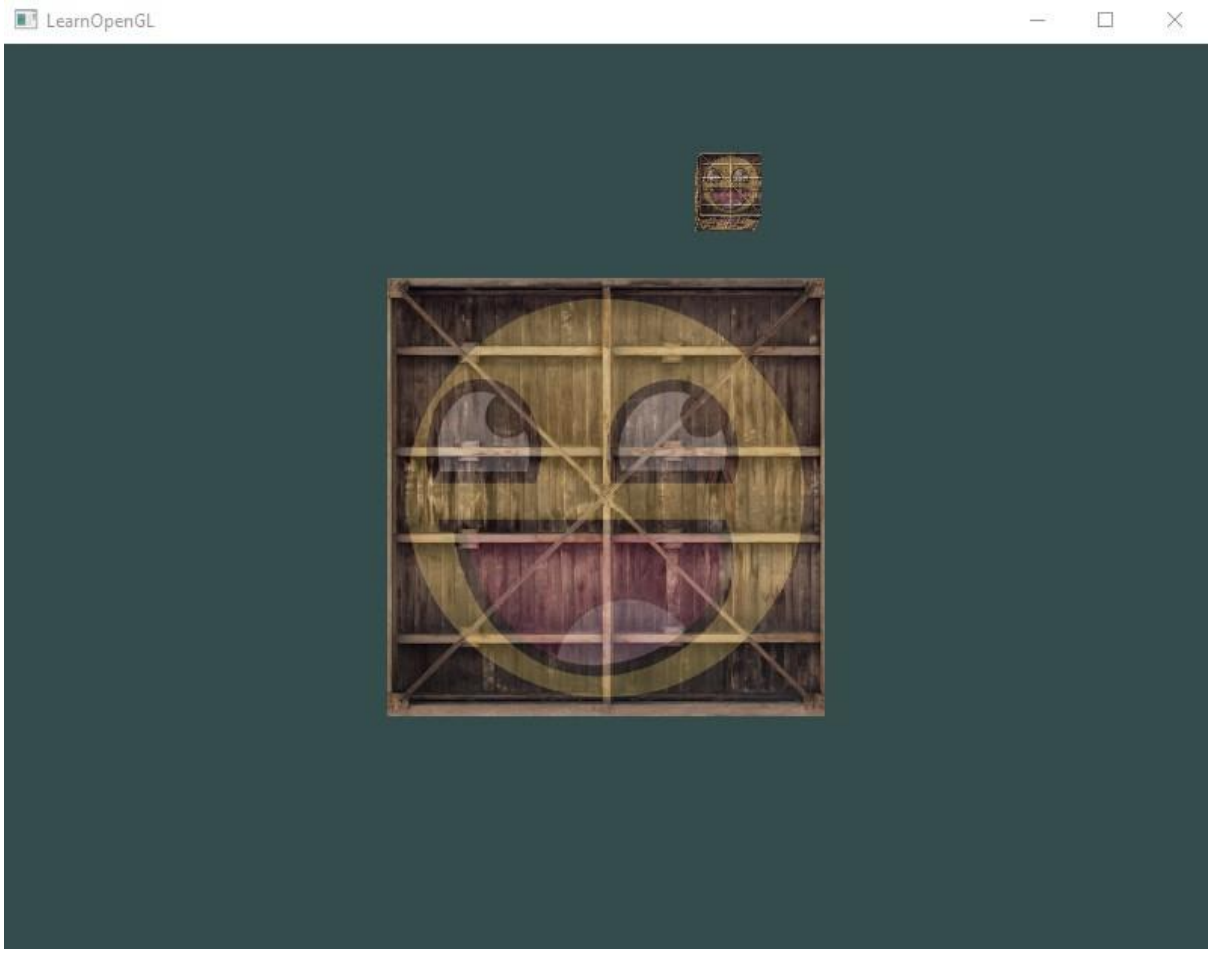
```
void main()
{
     FragColor = mix(texture(texture1, TexCoord),
texture(texture2, TexCoord), 0.2);
}
```

**Output (ScreenShot):**

a)



b)




c)

**Lab Task Q2**

**Question: Show an OpenGL program which will show a very shinny 3d colored cube which will be lighted by another 3d white colored cube where:**

**a) Camera: Camera will move along the +x axis with time.**

**b) Lighting: 40% diffuse +50% specular**

**Solution (Bold your own written code):**

**main.cpp**

```
#include "glad.h"
#include "glfw3.h"

#define STB_IMAGE_IMPLEMENTATION
#include "stb_image.h"

#include "glm/glm.hpp"
#include "glm/gtc/matrix_transform.hpp"

#include "learnopengl/shader_m.h"
#include <iostream>

void framebuffer_size_callback(GLFWwindow* window, int
width, int height);
void mouse_callback(GLFWwindow* window, double xpos,
double ypos);
void scroll_callback(GLFWwindow* window, double xoffset,
double yoffset);
void processInput(GLFWwindow *window);

// settings
const unsigned int SCR_WIDTH = 800;
const unsigned int SCR_HEIGHT = 600;

// camera
glm::vec3 cameraPos   = glm::vec3(0.0f, 0.0f, 3.0f);
glm::vec3 cameraFront = glm::vec3(0.0f, 0.0f, -1.0f);
glm::vec3 cameraUp    = glm::vec3(0.0f, 1.0f, 0.0f);

bool firstMouse = true;
float yaw   = -90.0f;  // yaw is initialized to -90.0
degrees since a yaw of 0.0 results in a direction vector
pointing to the right so we initially rotate a bit to
the left.
float pitch =  0.0f;
float lastX =  800.0f / 2.0;
float lastY =  600.0 / 2.0;
float fov   =  45.0f;

// timing
float deltaTime = 0.0f;// time between current frame and
```

```
last frame
float lastFrame = 0.0f;

// lighting
glm::vec3 lightPos(1.2f, 1.0f, 2.0f);

int main()
{
    // glfw: initialize and configure
    // ------------------------------
    glfwInit();
    glfwWindowHint(GLFW_CONTEXT_VERSION_MAJOR, 3);
    glfwWindowHint(GLFW_CONTEXT_VERSION_MINOR, 3);
    glfwWindowHint(GLFW_OPENGL_PROFILE,
GLFW_OPENGL_CORE_PROFILE);

#ifdef __APPLE__
    glfwWindowHint(GLFW_OPENGL_FORWARD_COMPAT, GL_TRUE);
#endif

    // glfw window creation
    // --------------------
    GLFWwindow* window = glfwCreateWindow(SCR_WIDTH,
SCR_HEIGHT, "LearnOpenGL", NULL, NULL);
    if (window == NULL)
    {
        std::cout << "Failed to create GLFW window" <<
std::endl;
        glfwTerminate();
        return -1;
    }
    glfwMakeContextCurrent(window);
    glfwSetFramebufferSizeCallback(window,
framebuffer_size_callback);
    glfwSetCursorPosCallback(window, mouse_callback);
    glfwSetScrollCallback(window, scroll_callback);

    // tell GLFW to capture our mouse
    glfwSetInputMode(window, GLFW_CURSOR,
GLFW_CURSOR_DISABLED);

    // glad: load all OpenGL function pointers
    // ---------------------------------------
    if
(!gladLoadGLLoader((GLADloadproc)glfwGetProcAddress))
    {
```

```
        std::cout << "Failed to initialize GLAD" <<
std::endl;
        return -1;
    }

    // configure global opengl state
    // -----------------------------
    glEnable(GL_DEPTH_TEST);

    // build and compile our shader program
    // ------------------------------------
    Shader
lightingShader("src/shader/template2_lighting.vs",
"src/shader/template2_lighting.fs");
    Shader
lightCubeShader("src/shader/template2_light_cube.vs",
"src/shader/template2_light_cube.fs");

    // set up vertex data (and buffer(s)) and configure
vertex attributes
    // ------------------------------------------------
-----------------
    float vertices[] = {
        -0.5f, -0.5f, -0.5f,  0.0f,  0.0f, -1.0f,
         0.5f, -0.5f, -0.5f,  0.0f,  0.0f, -1.0f,
         0.5f,  0.5f, -0.5f,  0.0f,  0.0f, -1.0f,
         0.5f,  0.5f, -0.5f,  0.0f,  0.0f, -1.0f,
        -0.5f,  0.5f, -0.5f,  0.0f,  0.0f, -1.0f,
        -0.5f, -0.5f, -0.5f,  0.0f,  0.0f, -1.0f,

        -0.5f, -0.5f,  0.5f,  0.0f,  0.0f,  1.0f,
         0.5f, -0.5f,  0.5f,  0.0f,  0.0f,  1.0f,
         0.5f,  0.5f,  0.5f,  0.0f,  0.0f,  1.0f,
         0.5f,  0.5f,  0.5f,  0.0f,  0.0f,  1.0f,
        -0.5f,  0.5f,  0.5f,  0.0f,  0.0f,  1.0f,
        -0.5f, -0.5f,  0.5f,  0.0f,  0.0f,  1.0f,

        -0.5f,  0.5f,  0.5f, -1.0f,  0.0f,  0.0f,
        -0.5f,  0.5f, -0.5f, -1.0f,  0.0f,  0.0f,
        -0.5f, -0.5f, -0.5f, -1.0f,  0.0f,  0.0f,
        -0.5f, -0.5f, -0.5f, -1.0f,  0.0f,  0.0f,
        -0.5f, -0.5f,  0.5f, -1.0f,  0.0f,  0.0f,
        -0.5f,  0.5f,  0.5f, -1.0f,  0.0f,  0.0f,

         0.5f,  0.5f,  0.5f,  1.0f,  0.0f,  0.0f,
         0.5f,  0.5f, -0.5f,  1.0f,  0.0f,  0.0f,
```

```
         0.5f, -0.5f, -0.5f,  1.0f,  0.0f,  0.0f,
         0.5f, -0.5f, -0.5f,  1.0f,  0.0f,  0.0f,
         0.5f, -0.5f,  0.5f,  1.0f,  0.0f,  0.0f,
         0.5f,  0.5f,  0.5f,  1.0f,  0.0f,  0.0f,

        -0.5f, -0.5f, -0.5f,  0.0f, -1.0f,  0.0f,
         0.5f, -0.5f, -0.5f,  0.0f, -1.0f,  0.0f,
         0.5f, -0.5f,  0.5f,  0.0f, -1.0f,  0.0f,
         0.5f, -0.5f,  0.5f,  0.0f, -1.0f,  0.0f,
        -0.5f, -0.5f,  0.5f,  0.0f, -1.0f,  0.0f,
        -0.5f, -0.5f, -0.5f,  0.0f, -1.0f,  0.0f,

        -0.5f,  0.5f, -0.5f,  0.0f,  1.0f,  0.0f,
         0.5f,  0.5f, -0.5f,  0.0f,  1.0f,  0.0f,
         0.5f,  0.5f,  0.5f,  0.0f,  1.0f,  0.0f,
         0.5f,  0.5f,  0.5f,  0.0f,  1.0f,  0.0f,
        -0.5f,  0.5f,  0.5f,  0.0f,  1.0f,  0.0f,
        -0.5f,  0.5f, -0.5f,  0.0f,  1.0f,  0.0f
    };

    // first, configure the cube's VAO (and VBO)
    unsigned int VBO, cubeVAO;
    glGenVertexArrays(1, &cubeVAO);
    glGenBuffers(1, &VBO);

    glBindBuffer(GL_ARRAY_BUFFER, VBO);
    glBufferData(GL_ARRAY_BUFFER, sizeof(vertices),
vertices, GL_STATIC_DRAW);
    glBindVertexArray(cubeVAO);

    // position attribute
    glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 6 *
sizeof(float), (void*)0);
    glEnableVertexAttribArray(0);
    // normal attribute
    glVertexAttribPointer(1, 3, GL_FLOAT, GL_FALSE, 6 *
sizeof(float), (void*)(3 * sizeof(float)));
    glEnableVertexAttribArray(1);


    // second, configure the light's VAO (VBO stays the
same; the vertices are the same for the light object
which is also a 3D cube)
    unsigned int lightCubeVAO;
    glGenVertexArrays(1, &lightCubeVAO);
    glBindVertexArray(lightCubeVAO);
```

```
    glBindBuffer(GL_ARRAY_BUFFER, VBO);
    // note that we update the lamp's position
attribute's stride to reflect the updated buffer data
    glVertexAttribPointer(0, 3, GL_FLOAT, GL_FALSE, 6 *
sizeof(float), (void*)0);
    glEnableVertexAttribArray(0);

    // render loop
    // -----------
    while (!glfwWindowShouldClose(window))
    {
        // per-frame time logic
        // --------------------
        float currentFrame =
static_cast<float>(glfwGetTime());
        deltaTime = currentFrame - lastFrame;
        lastFrame = currentFrame;

        // input
        // -----
        processInput(window);

        // render
        // ------
        glClearColor(0.2f, 0.3f, 0.3f, 1.0f);
        glClear(GL_COLOR_BUFFER_BIT |
GL_DEPTH_BUFFER_BIT); // also clear the depth buffer
now!

        // be sure to activate shader when setting
uniforms/drawing objects
        lightingShader.use();
        lightingShader.setVec3("objectColor", 1.0f,
0.5f, 0.31f);
        lightingShader.setVec3("lightColor", 1.0f, 1.0f,
1.0f);
        lightingShader.setVec3("lightPos", lightPos);
        lightingShader.setVec3("viewPos", cameraPos);

        // view/projection transformations
        glm::mat4 projection =
glm::perspective(glm::radians(fov), (float)SCR_WIDTH /
(float)SCR_HEIGHT, 0.1f, 100.0f);
        // camera transformation
        glm::mat4 view = glm::lookAt(cameraPos,
```

```
cameraPos + cameraFront, cameraUp);
        view = glm::translate(view, glm::vec3(0.5f, -
0.5f, 0.0f));
        view = glm::rotate(view, (float)glfwGetTime(),
glm::vec3(0.0f, 1.0f, 0.0f));

        // LightingShader
        glm::mat4 model = glm::mat4(1.0f);
        lightingShader.setMat4("projection",
projection);
        lightingShader.setMat4("view", view);
        lightingShader.setMat4("model", model);
        // render cube
        glBindVertexArray(cubeVAO);
        glDrawArrays(GL_TRIANGLES, 0, 36);

        // LightCubeShader
        lightCubeShader.use();
        lightCubeShader.setMat4("projection",
projection);
        lightCubeShader.setMat4("view", view);
        model = glm::mat4(1.0f);
        model = glm::translate(model, lightPos);
        model = glm::scale(model, glm::vec3(0.2f)); // a
smaller cube
        lightCubeShader.setMat4("model", model);
        // render lighting cube
        glBindVertexArray(lightCubeVAO);
        glDrawArrays(GL_TRIANGLES, 0, 36);

        // glfw: swap buffers and poll IO events (keys
pressed/released, mouse moved etc.)
        // -------------------------------------------
-------------------------------
        glfwSwapBuffers(window);
        glfwPollEvents();
    }

    // optional: de-allocate all resources once they've
outlived their purpose:
    // ------------------------------------------------
----------------------
    glDeleteVertexArrays(1, &cubeVAO);
    glDeleteVertexArrays(1, &lightCubeVAO);
    glDeleteBuffers(1, &VBO);
```

```
    // glfw: terminate, clearing all previously
allocated GLFW resources.
    // ------------------------------------------------
----------------
    glfwTerminate();
    return 0;
}

// process all input: query GLFW whether relevant keys
are pressed/released this frame and react accordingly
// ---------------------------------------------------
-----------------------------------------------
void processInput(GLFWwindow *window)
{
    if (glfwGetKey(window, GLFW_KEY_ESCAPE) ==
GLFW_PRESS)
        glfwSetWindowShouldClose(window, true);

    float cameraSpeed = static_cast<float>(1.0 *
deltaTime);

    if (glfwGetKey(window, GLFW_KEY_W) == GLFW_PRESS)
        cameraPos += cameraSpeed * cameraFront;

    if (glfwGetKey(window, GLFW_KEY_S) == GLFW_PRESS)
        cameraPos -= cameraSpeed * cameraFront;

    if (glfwGetKey(window, GLFW_KEY_A) == GLFW_PRESS)
        cameraPos -=
glm::normalize(glm::cross(cameraFront, cameraUp)) *
cameraSpeed;

    if (glfwGetKey(window, GLFW_KEY_D) == GLFW_PRESS)
        cameraPos +=
glm::normalize(glm::cross(cameraFront, cameraUp)) *
cameraSpeed;
}

// glfw: whenever the window size changed (by OS or user
resize) this callback function executes
// ---------------------------------------------------
---------------------------------------
void framebuffer_size_callback(GLFWwindow* window, int
width, int height)
{
    // make sure the viewport matches the new window
```

```
dimensions; note that width and
    // height will be significantly larger than
specified on retina displays.
    glViewport(0, 0, width, height);
}

// glfw: whenever the mouse moves, this callback is
called
// ------------------------------------------------------
--
void mouse_callback(GLFWwindow* window, double xposIn,
double yposIn)
{
    float xpos = static_cast<float>(xposIn);
    float ypos = static_cast<float>(yposIn);

    if (firstMouse)
    {
        lastX = xpos;
        lastY = ypos;
        firstMouse = false;
    }

    float xoffset = xpos - lastX;
    float yoffset = lastY - ypos; // reversed since y-
coordinates go from bottom to top
    lastX = xpos;
    lastY = ypos;

    float sensitivity = 0.1f; // change this value to
your liking
    xoffset *= sensitivity;
    yoffset *= sensitivity;

    yaw += xoffset;
    pitch += yoffset;

    // make sure that when pitch is out of bounds,
screen doesn't get flipped
    if (pitch > 89.0f)
        pitch = 89.0f;
    if (pitch < -89.0f)
        pitch = -89.0f;

    glm::vec3 front;
    front.x = cos(glm::radians(yaw)) *
```

```
cos(glm::radians(pitch));
    front.y = sin(glm::radians(pitch));
    front.z = sin(glm::radians(yaw)) *
cos(glm::radians(pitch));
    cameraFront = glm::normalize(front);
}

// glfw: whenever the mouse scroll wheel scrolls, this
callback is called
// ----------------------------------------------------
----------------
void scroll_callback(GLFWwindow* window, double xoffset,
double yoffset)
{
    fov -= (float)yoffset;
    if (fov < 1.0f)
        fov = 1.0f;
    if (fov > 45.0f)
        fov = 45.0f;
}
```

**vertex shader**

```
#version 330 core
layout (location = 0) in vec3 aPos;
layout (location = 1) in vec3 aNormal;

out vec3 FragPos;
out vec3 Normal;

uniform mat4 model;
uniform mat4 view;
uniform mat4 projection;

void main()
{
    FragPos = vec3(model * vec4(aPos, 1.0));
    Normal = mat3(transpose(inverse(model))) * aNormal;

    gl_Position = projection * view * vec4(FragPos,
1.0);
}
```

**fragment shader [Q2(a)]**

```
#version 330 core
```

```
out vec4 FragColor;

in vec3 Normal;
in vec3 FragPos;

uniform vec3 lightPos;
uniform vec3 viewPos;
uniform vec3 lightColor;
uniform vec3 objectColor;

void main()
{
    // ambient
    float ambientStrength = 0.1;
    vec3 ambient = ambientStrength * lightColor;

    // diffuse
    vec3 norm = normalize(Normal);
    vec3 lightDir = normalize(lightPos - FragPos);
    float diff = max(dot(norm, lightDir), 0.0);
    vec3 diffuse = diff * lightColor;

    // specular
    float specularStrength = 1.0;
    vec3 viewDir = normalize(viewPos - FragPos);
    vec3 reflectDir = reflect(-lightDir, norm);
    float spec = pow(max(dot(viewDir, reflectDir), 0.0),
4);
    vec3 specular = specularStrength * spec *
lightColor;

    vec3 result = (specular) * objectColor;
    FragColor = vec4(result, 1.0);
}
```

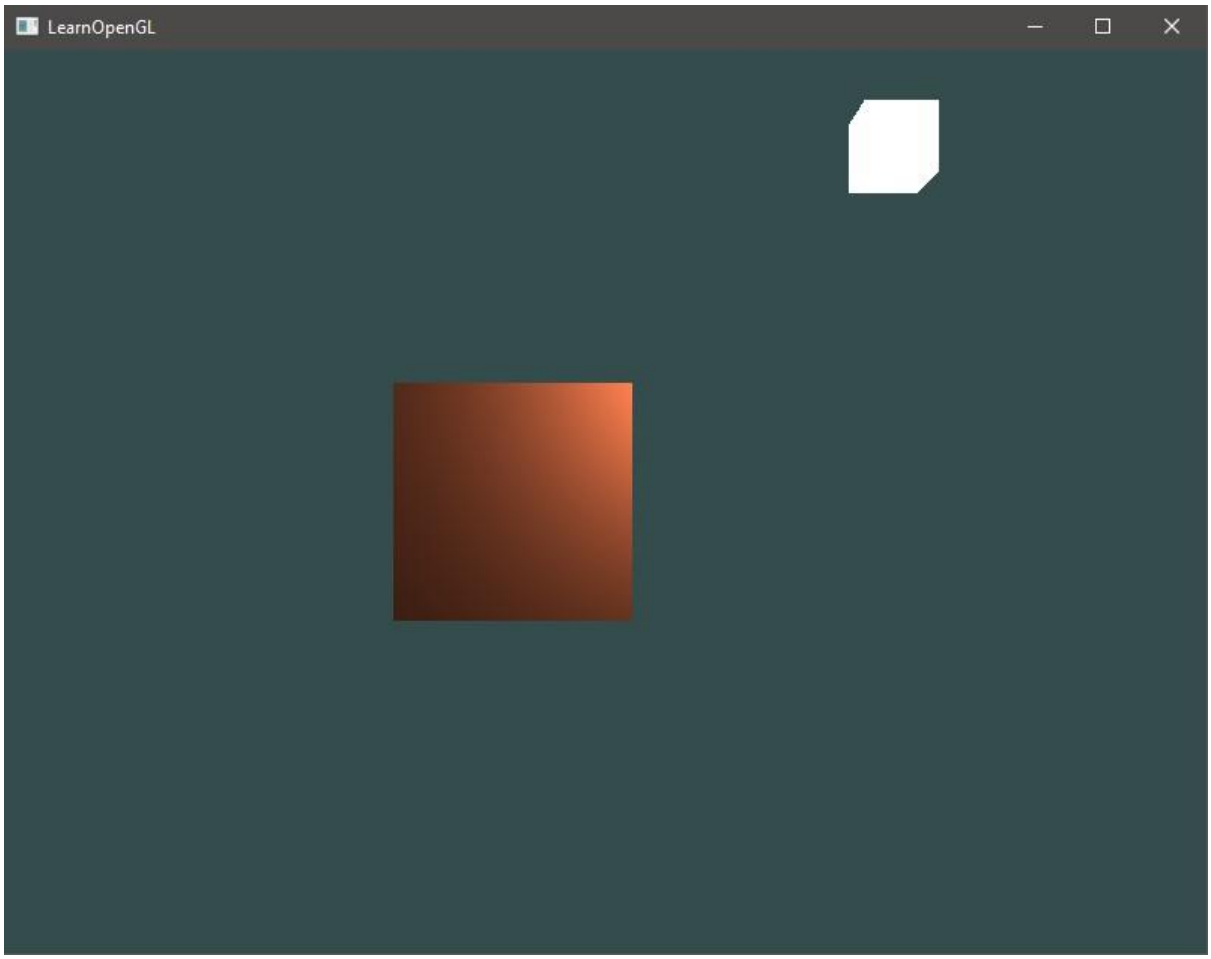
**fragment shader [Q2(b)]**

```
#version 330 core
out vec4 FragColor;

in vec3 Normal;
in vec3 FragPos;

uniform vec3 lightPos;
uniform vec3 viewPos;
```

```
uniform vec3 lightColor;
uniform vec3 objectColor;

void main()
{
    // ambient
    float ambientStrength = 0.1;
    vec3 ambient = ambientStrength * lightColor;

    // diffuse
    float diffuseStrength = 0.4;
    vec3 norm = normalize(Normal);
    vec3 lightDir = normalize(lightPos - FragPos);
    float diff = max(dot(norm, lightDir), 0.0);
    vec3 diffuse = diff * lightColor * diffuseStrength;

    // specular
    float specularStrength = 0.5;
    vec3 viewDir = normalize(viewPos - FragPos);
    vec3 reflectDir = reflect(-lightDir, norm);
    float spec = pow(max(dot(viewDir, reflectDir), 0.0),
4);
    vec3 specular = specularStrength * spec *
lightColor;

    vec3 result = (diffuse + specular) * objectColor;
    FragColor = vec4(result, 1.0);
}
```

**Output (ScreenShot):**

a)



b)