INTERACTIVE BIOLOGICAL MODELS WITH BBC MICRO:BIT AND SMART LED CODING: A STEAM APPROACH TO VISUALIZING LIVER PHYSIOLOGY AND BLOOD CIRCULATION

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Abstract

The integration of Science, Technology, Engineering, Arts and Mathematics (STEAM) in science education provides opportunities for students to explore complex scientific concepts through practical, interdisciplinary activities. This paper presents an educational project designed to facilitate the understanding of human liver physiology and hepatic blood circulation through the construction of interactive three-dimensional anatomical models using recycled materials, BBC micro:bit microcontrollers and programmable LED circuits.
The project involved students aged 12–14 years and was implemented over four 45-minute lessons. The learning process combined biological investigation, physical model construction, basic electronic circuit assembly and block-based programming using Microsoft MakeCode. Students explored the dual blood supply of the liver, identifying the hepatic artery, hepatic portal vein and hepatic veins, and represented the movement of blood through colour-coded LED sequences.
The activity followed a collaborative, project-based learning approach in which students participated in investigating, designing, constructing, programming, testing and presenting their models. Red and blue LEDs were used as simplified visual representations of differences in blood oxygenation and circulation pathways. Recycled and low-cost materials made the activity accessible and adaptable to different school environments.
The project demonstrates how physical computing and interdisciplinary model construction can be incorporated into biology lessons to support the visualization of otherwise abstract physiological processes. It also provides opportunities for developing computational thinking, problem-solving, creativity, collaboration and scientific communication.

Keywords: STEAM education, BBC micro:bit, liver physiology, blood circulation, physical computing, interactive biological models, project-based learning, low-cost experiments.

Introduction and theoretical background

The teaching of human anatomy and physiology in lower secondary education presents several pedagogical challenges, particularly when students are expected to understand biological processes that cannot be directly observed. Internal organ structures, blood circulation and the physiological functions of the liver are commonly introduced through textbook illustrations, diagrams and verbal explanations. Although these resources provide essential theoretical information, they may not sufficiently demonstrate the dynamic nature of physiological processes.
The liver is one of the most metabolically active organs in the human body and performs essential functions related to nutrient metabolism, storage, detoxification and the synthesis of biologically important substances. Its blood supply is particularly interesting from an educational perspective because it receives blood through two distinct vascular systems: the hepatic artery and the hepatic portal vein. The hepatic veins subsequently drain blood from the liver into the inferior vena cava (Harkins & Ahmad, 2023; StatPearls, 2023).
Approximately 75–80% of hepatic blood flow is supplied by the portal vein, while the remaining 20–25% is provided by the hepatic artery. The portal vein transports blood containing absorbed nutrients from the digestive organs, whereas the hepatic artery provides oxygen-rich blood. Both contribute to the liver's metabolic activity (StatPearls, 2023).

Understanding these anatomical and physiological relationships requires students to connect the structure of the circulatory system with its functional significance. For this reason, the use of three-dimensional models and interactive technological resources can provide an alternative to exclusively theoretical instruction.

Integrated STEM education encourages the application of knowledge from different disciplines to solve authentic problems(Ademi et al.,2023). A systematic review by McLure et al. (2022) emphasizes the importance of interdisciplinary projects that combine scientific knowledge, engineering design, technological applications and collaborative learning in middle and secondary school education.

Similarly, project-based learning provides opportunities for students to actively participate in the design and development of practical solutions. Research by Santhosh et al. (2023) indicates that project-based STEM learning can positively contribute to students' learning outcomes.

Within this educational framework, the present project combines biological knowledge with physical computing through the BBC micro:bit platform. By programming LED sequences and integrating them into three-dimensional anatomical models, students can represent blood circulation through visual and interactive simulations.

The central guiding question of the project was:

How can low-cost digital technologies and physical models be used to visualize the structure of the liver and demonstrate blood circulation in an interactive and understandable way?

Aim and objectives

The main aim of this project was to develop, construct and program interactive three-dimensional anatomical models of the human liver and its vascular system using recycled materials, BBC micro:bit microcontrollers and programmable LED components.

The project aimed to connect theoretical biological knowledge with practical technological applications through an interdisciplinary STEAM learning environment.

Specific objectives

The project pursued the following objectives:

1. To develop students' understanding of the anatomical structure and physiological functions of the human liver.
2. To identify the main blood vessels associated with hepatic circulation: the hepatic artery, hepatic portal vein and hepatic veins.
3. To distinguish between blood with different levels of oxygenation and understand the liver's dual blood supply.
4. To introduce students to basic electronic circuits, microcontrollers and block-based programming.
5. To develop practical skills in designing and constructing three-dimensional biological models using accessible and recycled materials.
6. To encourage computational thinking through programming LED sequences and controlling digital outputs.
7. To strengthen collaboration, creativity, problem-solving and scientific communication through group-based activities.

Interdisciplinary STEAM integration

The project integrated five educational areas:

STEAM area	Educational content and activities
Science	Human anatomy, liver physiology, hepatic circulation and blood oxygenation.
Technology	BBC micro:bit, digital outputs and Microsoft MakeCode.
Engineering	Designing, assembling and testing electronic circuits and three-dimensional models.
Arts	Designing and decorating anatomical models using recycled and creative materials.
Mathematics	Sequencing, timing, proportional representation and logical programming operations.

This interdisciplinary structure allowed students to apply knowledge and skills from different subjects within a common practical task. Rather than studying biological, technological and mathematical concepts separately, students used them together to develop a functional educational prototype (Jashari et al., 2022).

4. Materials and technological resources

The project was designed around low-cost, easily accessible materials to ensure that it could be implemented in ordinary school laboratory or classroom environments.

4.1. Biological and construction materials
4.2.

- Recycled cardboard and cardboard boxes.
- Papier-mâché and modelling clay/plasticine.
- Acrylic paints, brushes and coloured markers.
- Transparent plastic tubes representing blood vessels.
- Scissors, rulers and hot glue.
- Supporting materials for assembling and stabilizing the models.

4.2. Electronic and technological equipment

- BBC micro:bit microcontroller boards.
- Micro-USB cables and battery packs.
- Red and blue LEDs or compatible LED strips.
- Crocodile clip leads.
- Appropriate resistors for individual LEDs.
- External electronic drivers or transistor modules when required for LED strips.
- Computer or laptop for programming.

Digital tools

Microsoft MakeCode for micro:bit was used as the main programming environment. Its visual block-based interface enables students to develop basic programming logic without requiring previous experience in text-based programming (Microsoft MakeCode, n.d.).
The main programming functions included:

- Button A and Button B input events.

- Digital output control.
- Sequential LED activation.
- Timing and pauses between programmed actions.

Official programming resource: Microsoft MakeCode for micro:bit.

Methodology and implementation of the project

Educational design

The project was implemented through a project-based, collaborative learning approach involving four consecutive lessons of 45 minutes each.
Students worked in small groups, with each group participating in the biological investigation, model design, construction, programming and final presentation.
The methodological process consisted of five interconnected stages:

1. Biological investigation and conceptual understanding.
2. Design and construction of the physical model.
3. Electronic circuit assembly.
4. Programming and system integration.
5. Testing, presentation and evaluation.

The learning process followed an iterative design approach in which students were encouraged to test their constructions, identify technical problems and make necessary adjustments.

Lesson 1 – Biological investigation and introduction to electronic circuits

The first lesson focused on developing the theoretical knowledge required for the construction of the anatomical models.

Students investigated the structure and main physiological functions of the human liver, paying particular attention to its blood supply and venous drainage.
The following structures were identified and discussed:

- Hepatic artery: transports oxygen-rich blood to the liver.
- Hepatic portal vein: transports nutrient-rich blood from the digestive organs to the liver. Its oxygen content is lower than that of arterial blood, but it is not completely deoxygenated.
- Hepatic veins: transport blood away from the liver towards the inferior vena cava.

Students examined diagrams of hepatic circulation and prepared simplified flowcharts illustrating the direction of blood movement.

Following the biological investigation, students were introduced to the basic principles of electronic circuits and the BBC micro:bit microcontroller. They explored the function of digital input and output pins and learned how programmed signals can activate external LEDs.

This introductory activity established the connection between biological processes and their technological representation.

Lesson 2 – Three-dimensional anatomical modelling and design

During the second lesson, students transformed their theoretical knowledge into physical representations.
Working in groups, they designed and constructed three-dimensional models of the human liver using recycled cardboard, papier-mâché, modelling materials and paint.
The main construction stages included:

1. Preparing the supporting structure of the liver model.

2. Shaping and assembling the main anatomical representation.
3. Identifying the approximate positions of the hepatic artery, portal vein and hepatic veins.
4. Attaching transparent tubes along the pathways representing the blood vessels.
5. Planning the positions of the red and blue LED components.
6. Decorating and labelling the model to improve anatomical identification.

Red and blue colours were selected to represent differences in blood oxygenation and facilitate the visual interpretation of circulation.
The students were encouraged to consider the anatomical arrangement of the structures and the direction of blood movement when positioning the vascular pathways.

Lesson 3 – Programming and electronic integration

The third lesson focused on integrating the electronic components with the physical anatomical models.
Using Microsoft MakeCode, students developed simple block-based programs to control LED activation through the BBC micro:bit.
Two principal programming sequences were designed.
Sequence A – Representation of oxygen-rich blood flow
When Button A was pressed, the micro:bit activated the red LEDs in a sequential pattern along the pathway representing the hepatic artery.
Sequence B – Representation of hepatic venous drainage
When Button B was pressed, the blue LEDs were activated sequentially along the pathways representing the hepatic venous drainage.
The activation intervals were adjusted to create a visible movement effect and demonstrate the direction of circulation.
Students tested the connections, examined the functionality of the electronic components and modified the programming sequences when technical problems occurred.
The use of digital outputs allowed students to understand how a simple programmed instruction could control an external electronic component. The micro:bit documentation describes these pins as programmable digital input/output connections, including P0, P1 and P2 (Micro:bit Educational Foundation, n.d.).
Microsoft MakeCode for micro:bit
Technical consideration: Individual LEDs should be connected with suitable current-limiting resistors. LED strips must not be powered directly from GPIO pins; appropriate external power and driver circuits should be used, with a common ground where required.

Lesson 4 – Model finalization, testing and student presentations

The final lesson was dedicated to completing and presenting the interactive anatomical models. Students integrated the programmed micro:bit boards, LED components and physical structures into their final prototypes.
Each group demonstrated the operation of its model and explained the biological processes represented through the programmed light sequences.
During the presentations, students were encouraged to explain:

- The main anatomical structures of the liver.
- The difference between hepatic arterial and portal venous blood supply.
- The direction of hepatic venous drainage.
- The relationship between the biological structures and the electronic components.
- The role of programming in controlling the visual simulation.

Peer discussion was encouraged to promote scientific communication, collaborative learning and critical evaluation of the developed models.

Results

The implementation of the project resulted in the development of interactive three-dimensional anatomical models combining biological structures with programmable electronic components. The main educational and practical outcomes included:

1. Development of physical models
   Students constructed three-dimensional representations of the liver and its associated vascular pathways using recycled and low-cost materials.
2. Integration of electronic components
   The models incorporated BBC micro:bit microcontrollers and red and blue LED components, enabling the visual representation of blood circulation through programmed light sequences.
3. Development of basic programming skills
   Students used Microsoft MakeCode to create simple algorithms involving button-controlled inputs, digital outputs and sequential activation of LEDs.
4. Interdisciplinary learning
   The activity connected biological concepts with technological applications, engineering design, mathematical sequencing and artistic construction.
5. Collaborative learning and scientific communication
   Group activities and final presentations provided opportunities for students to explain their models, exchange ideas and demonstrate the relationship between theoretical knowledge and practical applications.

Discussion and reflection

The project demonstrates a practical approach to integrating biological content with digital technologies in lower secondary education.

One of its main educational advantages is the transformation of abstract physiological concepts into visible and interactive representations. Through the use of three-dimensional structures and programmed LED sequences, students could follow the pathways of hepatic circulation and connect anatomical structures with their physiological roles.

The integration of BBC micro:bit introduced students to physical computing in a biological context. Instead of using programming exclusively for conventional computational exercises, students applied coding to represent a biological process.

The construction process also provided opportunities for engineering design and problem-solving. Students had to consider the dimensions and arrangement of the model, the positioning of electronic components and the functionality of the circuits. Technical challenges, such as incorrect connections or programming errors, required testing, troubleshooting and modification.

These characteristics are consistent with the principles of integrated STEM education, in which students apply knowledge from several disciplines to develop practical solutions to authentic problems (McLure et al., 2022, Jashari et al., 2024).

Furthermore, the collaborative and project-based structure of the activity is supported by research highlighting the educational potential of practical STEM projects and their contribution to student learning (Santhosh et al., 2023).

Evaluation of the project

The evaluation was based on the observation of student participation, the quality of the constructed models, the functionality of the electronic components and the clarity of the final presentations.

The following criteria were considered:

Evaluation criterion	Indicators
Biological accuracy	Correct identification and representation of hepatic structures and blood pathways.
Model construction	Stability, organization and appropriate use of materials.
Electronic functionality	Correct connections and successful LED activation.
Programming	Appropriate use of inputs, outputs and sequential commands.
Collaboration	Participation, communication and distribution of group responsibilities.
Scientific presentation	Ability to explain the model and relate it to biological concepts.

Student reflection focused on identifying the relationship between the physical model and the biological process, recognizing technical challenges and evaluating how digital technologies contributed to the learning experience.
An important methodological consideration is that the LED representation is a simplified educational simulation. In particular, the portal vein should not be represented as carrying completely deoxygenated blood. Its blood is nutrient-rich and relatively less oxygenated than arterial blood. Therefore, the colours serve as visual teaching conventions rather than exact measurements of blood oxygen saturation.
Although the project provides qualitative evidence through the developed models and student demonstrations, quantitative claims about improvements in academic achievement would require additional assessment, such as pre- and post-activity knowledge tests.

Conclusion

The project Interactive Biological Models with BBC micro:bit and Smart LED Coding illustrates how interdisciplinary STEAM activities can enrich the teaching of human anatomy and physiology in lower secondary education.
By combining recycled materials, three-dimensional model construction, electronic circuits and block-based programming, students were provided with opportunities to explore hepatic circulation through practical and interactive learning experiences.
The project connected biological knowledge with technological literacy, engineering design, mathematical reasoning and artistic creativity. It also encouraged collaboration, problem-solving and scientific communication.
An important characteristic of this activity is its adaptability. The use of low-cost materials and accessible digital tools makes it possible for other teachers to implement similar activities without requiring specialized laboratory infrastructure.
Overall, the project provides a replicable methodological example of how physical computing can be incorporated into biology education to make complex scientific concepts more accessible, interactive and meaningful to students.

Illustrative material and documentation of the activity

The following visual documentation is recommended to demonstrate the implementation process and the final educational outcomes.

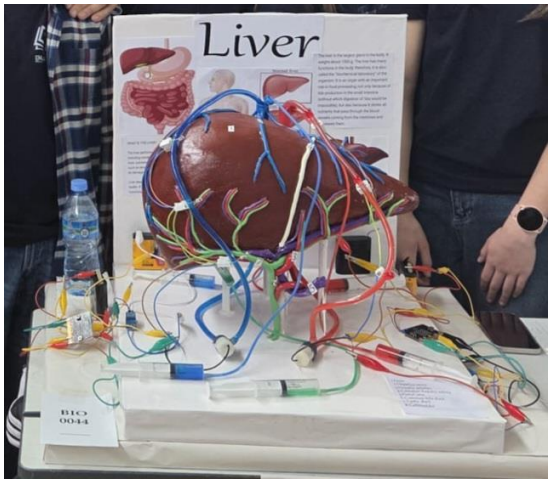

Figure 1. Construction of the three-dimensional liver model.

Photographs showing students designing and constructing the anatomical model using recycled cardboard, modelling materials and coloured paint.

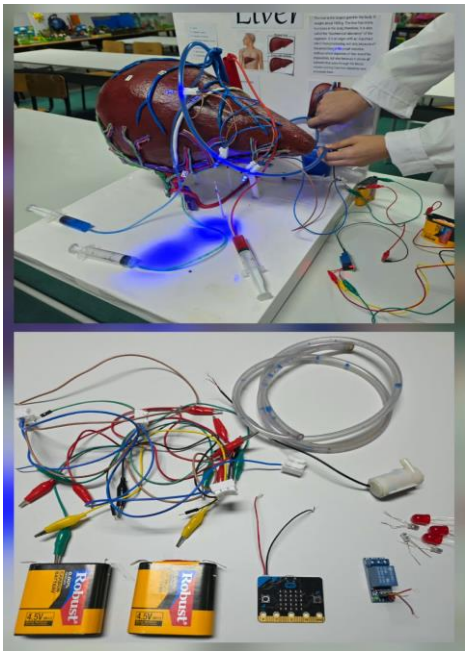

Figure 2. Electronic circuit assembly and BBC micro:bit integration.

Photographs illustrating the connection of the micro:bit board, electronic components and red and blue LED pathways.A screenshot of the block-based programming interface showing the programmed sequences for controlling the LEDs through Button A and Button B.

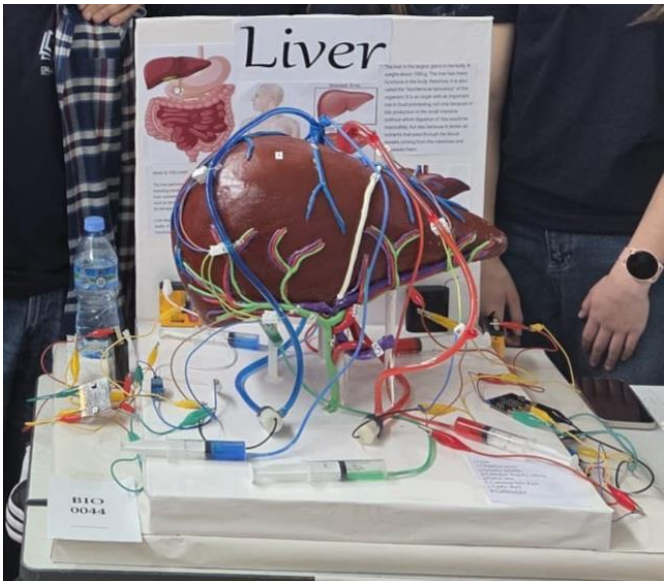

Figure 3. Final interactive anatomical model.

Photographs of the completed model during classroom demonstrations, illustrating the programmed LED sequences and students' explanations of hepatic circulation.

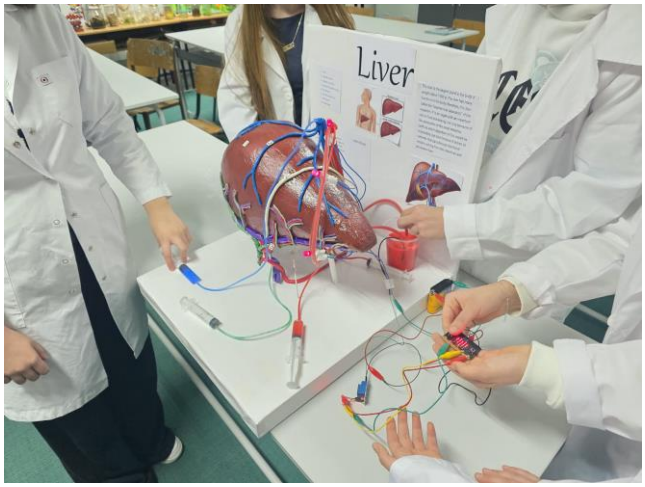

Figure 4. Student presentation and collaborative learning

Photographs documenting group presentations, student interaction and the explanation of biological and technological concepts.

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