# EDUCATION ON TECHNOLOGIES: THE PROTOTYPE OF A HEART BLOOD PRESSURE SIMULATOR AS AN INTERDISCIPLINARY TOOL

Bernardo Ternus de Abreu, Caio Francisco Ternus de Abreu, Gabriela Luísa Schmitz

Abstract: In this article, we intend to present a prototype of an invasive blood pressure (IBP) pneumatic simulator, which simulates part of the heart function, as a technological tool for processes of education in schools or non-formal educational spaces, such as museums. The article contains a description of the process of prototype development with a view to free reproduction by secondary students.

Keywords: heart, simulator, education, schools.

Resumo: Neste artigo, pretendemos apresentar um protótipo de simulador pneumático de pressão arterial invasiva (PII), que simula parte da função cardíaca, como ferramenta tecnológica para processos educacionais em escolas ou espaços educacionais não formais, como museus. O artigo contém uma descrição do processo de desenvolvimento de protótipos para reprodução livre por alunos do ensino médio.

Palavras-chave: coração, simulador, educação, escolas.

## 1 Introduction

Nowadays it is essential that students have a training that is, at the same time, humanized and able to introduce a reflexive thinking about issues that affect the common life of everyone. Also, training should lead to a familiarization to tech tools aiming to become technologically literate in a world increasingly digital and in constant transformation. Although the teaching content is very important, it is substantial the way it will be teached (Paiva et al., 2016). Considering the need and relevance of STEM (science, technology, engineering and math) disciplines in the scientific, economic and technological development of society, practices that involve students in STEM activities are encouraged (Bybee, 2010).

Among practices involving STEM that are possible to be developed in basic education, the production of physical and virtual models of human biological structures have shown to be effective in students development and learning (Oliveira et al., 2017). Although models can contribute to students' learning, it is only effective when the practice does not have an end in itself (Schmitz et al., 2020). In other words, practice should be structured in a way to develop skills and abilities, as those described in the Nacional Common Curricular Base (in Portuguese, Base Nacional Comum Curricular - BNCC, Brasil, 2017). The activities can be built using a living organism system, such as the cardiovascular system, as a central theme. Thereby, our manuscript aims to present a prototype of a system of “invasive blood pressure simulation”, described below.

## 2 The importance of technological literacy to future

Electronic and digital literacy is understood as a set of knowledge that allows people to engage in literate practices mediated by computers and electronic devices from the contemporary world (Silva, 2011). Once those knowledge are acquired, students are able to communicate in post-modern society in a more effective way. The post-modern society is constantly evolving in more and more global networks that end up inserted into people's daily routine. Also, the comprehension of the technological phenomenon is associated with a type of electronic citizen that involves the subject to be aware about their right to access information and communication networks (Ribeiro, 2008).

Considering the exposure above, we elaborate our prototype aiming to contribute to development of skills and abilities related to digital literacy, the STEM approach, using a common theme that is blood pressure. Our prototype can contribute to a rich learning experience for students.

## The heart, blood vessels and invasive blood pressure

The cardiovascular system is composed by an extensive and complex network of vessels, arteries, veins and capillaries that conduct blood along to the body and has the heart as main organ (Whitaker, 2010). In general, the heart can be described as a pump, responsible for the blood circulation in the body, situated in the thoracic cavity. The human heart is composed of four cavities: the right and left atria and the right and left ventricles. The right side of the human heart is responsible for pumping oxygen-poor blood for its correct oxygenation (WHITAKER, 2010; LOUKAS, 2009). In turn, left side of the human heart is the one that receives the oxygenated blood from the lungs. The oxygenated blood is strongly sent through the arteries to the organs and our prototype works in this way.

While pumping blood the heart performs movements: systole and diastole. In systole, the heart muscle contracts and blood is pumped to the aorta vein and pulmonary artery, which will spread blood into a network of blood vessels (Whitaker, 2010; Loukas, 2009). In diastole the heart muscle relaxes, allowing the blood to flow from the coronary and cava veins towards the heart filling its cavities (Whitaker, 2010; Loukas, 2009).

The maintenance of blood circulation is important once the blood is responsible to perform the transportation of oxygen, nutrients and proteins to the living tissues. In addition to transporting the necessary substances to the tissues to perform work, blood also transports cellular metabolites to tissues responsible for its excretion, which is the case of carbon dioxide ($CO_2$) and urea, for example.

One of the circulatory parameters considered when assessing patients' health state is blood pressure. In an adult subject the normal blood pressure conditions are systolic 12mmHg and diastolic 8 mmHg. To know the patient's blood pressure patterns is essential once sudden variations and the maintenance of high blood pressure indicates problems in the circulatory system that can cause tissues damage (Cowley Jr, 1992).

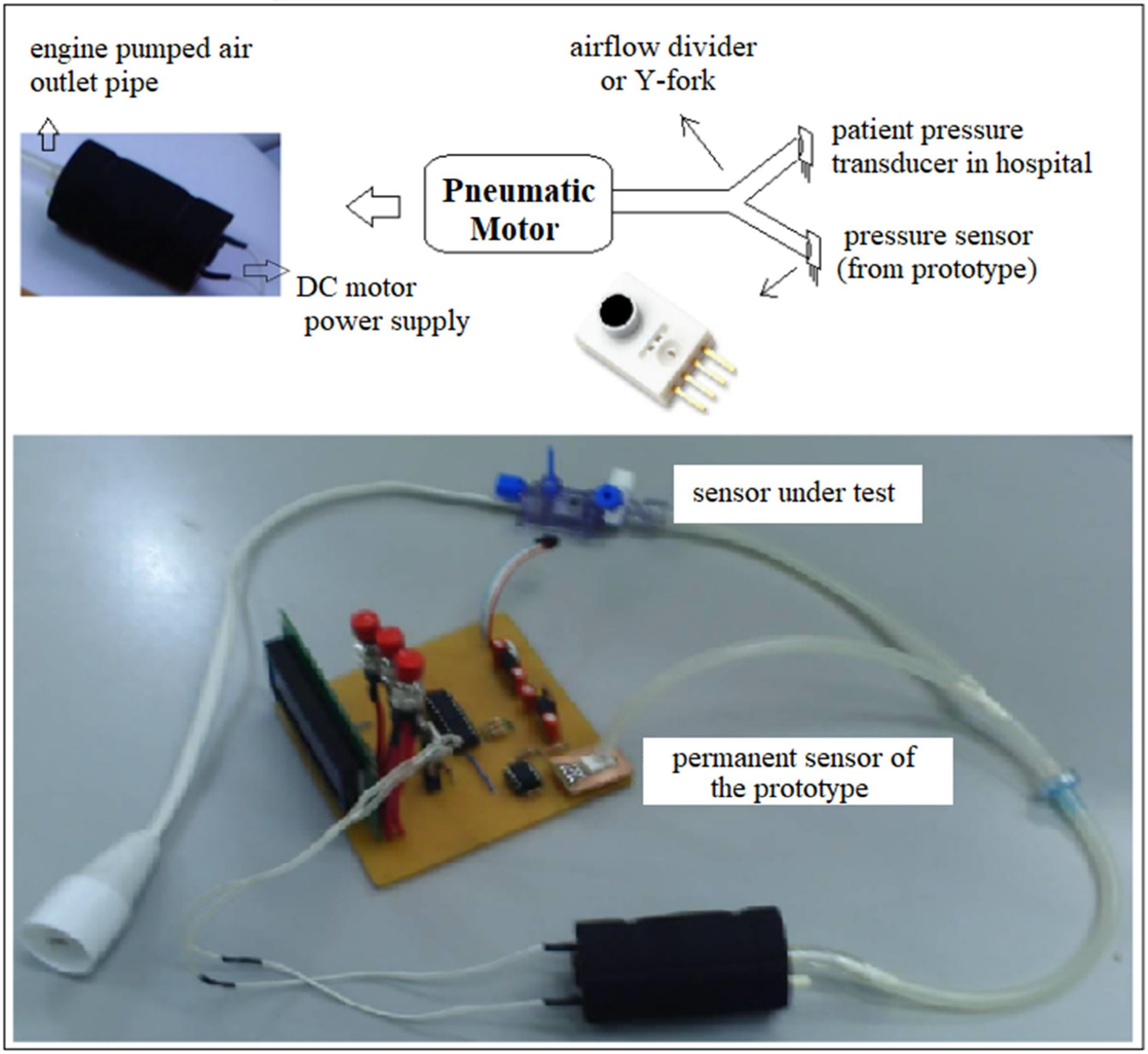
There are two main methods to monitorize blood pressure: invasive and non-invasive. The non-invasive method is the more known method, in which blood pressure is measured using a cuff on the patient's arm. The cuff is inflated until the radial pulse can be felt. The air, then, is released and the measurement is taken by reading a pressure gauge. In the non-invasive method the blood pressure is known in the moment of the measurement and its monitoring is done by measurement sequences (Cowley Jr, 1992).

Invasive blood pressure, abbreviated as IBP, is a system of continuous monitoring of blood pressure that uses a catheter inserted into the radial artery. Results are continuously displayed on a multiparameter monitor. The IBP is mainly used to avoid the constant handling of patients, as in cases of patients in hypertensive crisis, with significant and constant blood pressure changes, among other cases (Cowley Jr, 1992).

## 3 Projecting the prototype

The IBP simulator is nothing more than a machine that pumps air through a pneumatic motor. The engine sends air through a small tube that makes it press or deform a pressure sensor attached to it. The simulator is shown in Figure 1.

Figure 1 – System with a motor that pumps air to simulate the pumping of blood through the heart (blood pressure is simulated through air pressure, measured with Freescale's MPX2300DT1 sensor).

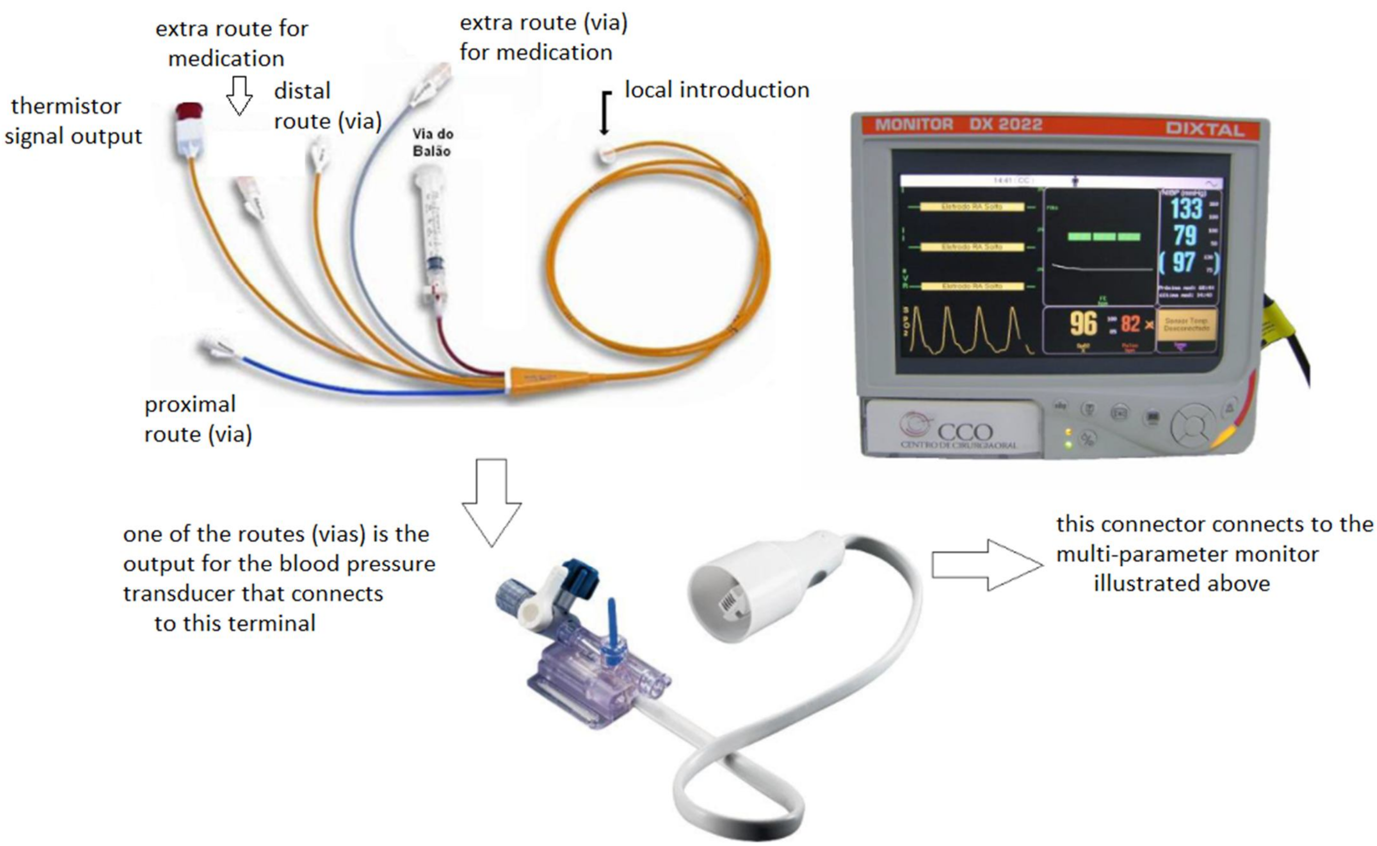



Source: adapted by the author.

In an organism, the heart is controlled by electrical impulses that trigger the muscle fibers to contract and extend, and consequently send blood through the arteries. In the case of the engine, which simulates the work of a heart, its control can be given electronically through a system whose central element is a microcontroller. The PIC16F690 microcontroller is an excellent option, easy to control. The configuration code for the microcontroller ports is available in the attachment, as well as the program that was developed to control the motor.

In a hospital, in an Intensive Care Unit, usually a patient who is monitoring their blood pressure in a bed uses a Swan-Ganz catheter attached to a pressure transducer. The catheter has a terminal to be deformed by the body, and this deformation is responsible for producing an electrical impulse in the conductor, which processes and amplifies it to graphically represent it on the screen of a hemodynamic monitor. This can be seen in Figure 2, below, which also shows a pressure transducer, which is attached to the monitor:

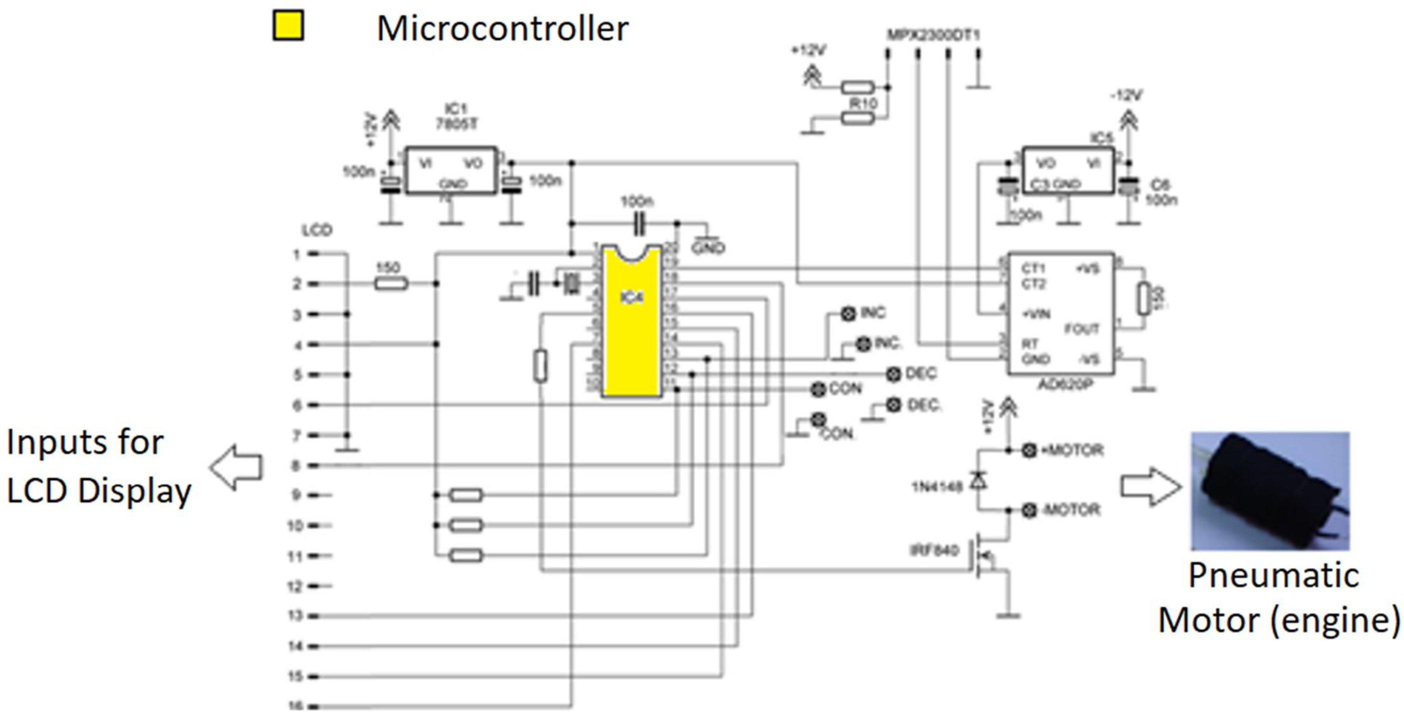
Figure 2 – Pressure measurement system with multiparameter monitor.




Source: adapted by the author (2021).

In this proposal, an activity can be developed using the IBP system prototype, which involves the design of an electronic circuit for implantation by the students, whose central element is a microcontroller responsible for regulating several functions, as shown in Figure 3:

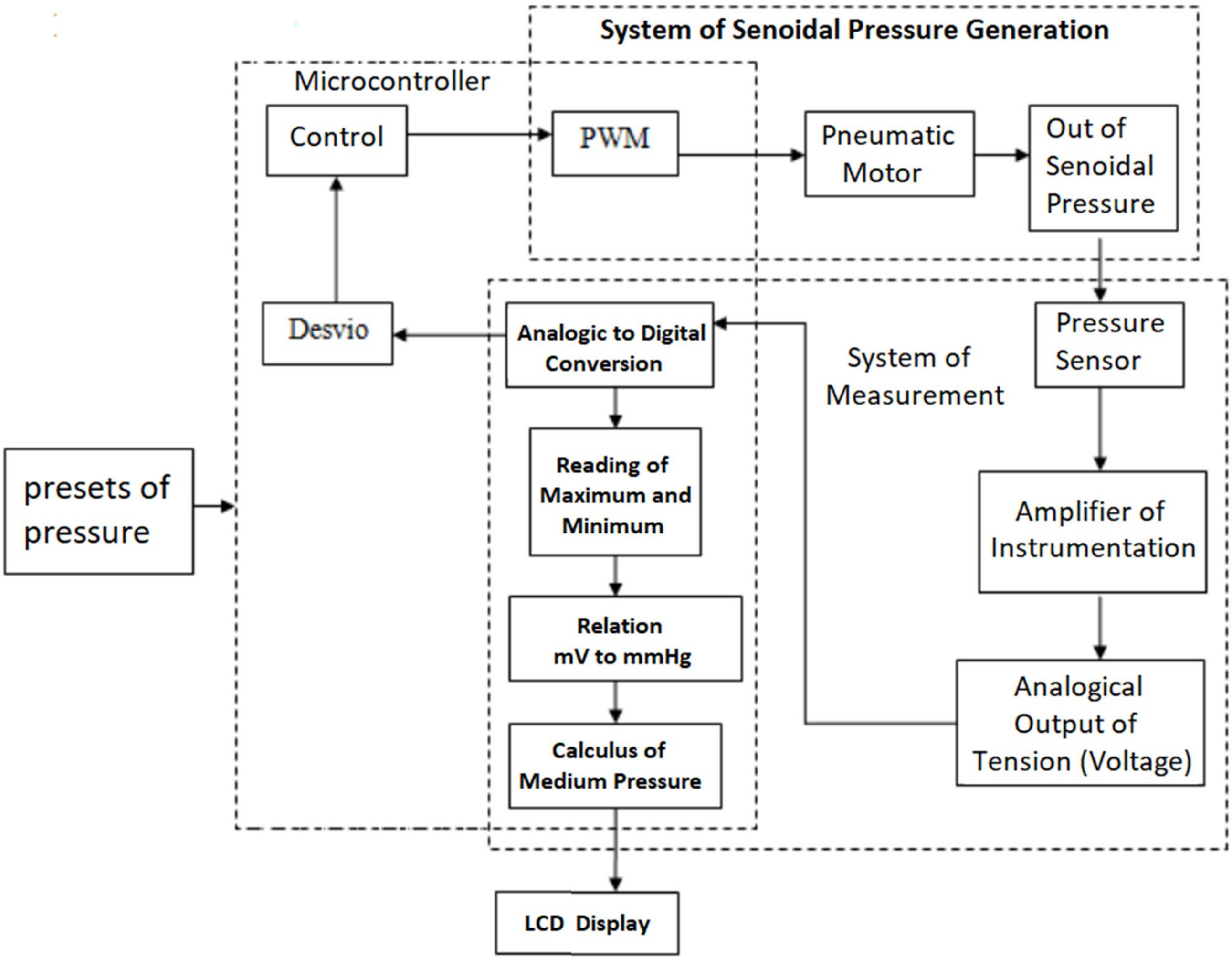
Figure 3 – IBP simulator prototype circuit.




Source: adapted by the authors (2021).

The logic of the internal program in the microcontroller is described in Figure 4 below, using a block diagram. The microcontroller is like a brain of the entire circuit's control architecture. It has signal inputs and outputs. Some signals arrive at its input, these analog signals, and are converted to digital, with a certain resolution, that is, a ratio, as a rule of three, between the analog values and each digital unit, in this case 255 bits. A reading of the maximum and minimum values takes place, they are converted to the millimeters of mercury scale, or mmHg, and then displayed on an LCD display. From the selection of presets, the microcontroller has a pulse width modulation system that controls the output signals, which are then read by itself and adjusted, this being a feedback of the circuit.

Figure 4 – Measurement system of the IBP simulator.




Source: adapted by the authors (2021).

The circuit illustrated above is composed of a NE555 voltage oscillator, responsible for producing quadratic pulses that are sent to an operational amplifier TL084, pass through a filter and arrive at a power transistor, which sends, with a higher current, a power supply for the pneumatic motor. The circuit for measuring the pressure pumped by the motor is made up of the microcontroller, which reads the signals and converts them into a scale of millimeters of mercury, mmHg, the same one that indicates blood pressure on a scale of, for example, 12 by 8.

These values are generally indicative of normal pressure values. Low pressures are set via a knob to a 9 by 6 preset or option ie 90 by 60 mmHg. The control system also allows high pressure values, such as 14 by 9. They are nothing more than values placed on a microcontroller input, in a ratio from 0 to 255.

Single output PWM signals (RC5 – pin 5) are sent to the IRF840, which is an N-channel MOSFET transistor. It receives the width-modulated pulse at the gate and switches the current into the load now and then, driving the OKEN SEIKO 6VDC pneumatic motor, which provides a sinusoidal air output. When it is on, it will cause a ground to be provided to the motor. When it is off, the engine ground is floating. The IRF840 has Vgs(th) from 2 to 4V (trigger voltage range), less than the 5V of the microcontroller's PWM output, thus ensuring switching.

The program's active cycles range from 0 to 50%, as +6V is the limit of the motor's rated output voltage according to its capacity, since its input voltage is +12V and its datasheet reports an output of 6V. These signals are sent to the pressure sensor MPX2300DT1 which converts from mechanical to electrical in the scale of 5uV / V / mmHg, that is, 5uV per supply volt. Considering that the maximum pressure in millimeters of mercury is 300mmHg, then since there is a voltage divider that supplies 9V of power to the sensor, the sensitivity scale is 5uV x 9V x 300 = 0.0135V.

As these signals are very low, they need to be amplified in order to be processed by the microcontroller (0.0135 x gain of 333 = 4.5V in the microcontroller). The AD620 is an instrumentation amplifier, therefore it features a high voltage common mode voltage rejection (CMRR) and is therefore intended for precision applications. The amplified signals are sent to the AN0 microcontroller's analogue-digital conversion channel, which processes the signals in 10 bits to display them on the LCD display at maximum, minimum and average values, which are important parameters in medicine. The 5 pressure presets listed above are selected by the selection knobs, which are three:

- INCREMENT button: Go to the above preset (RB4);
- DECREASE button: Go to the preset below (RB5);
- CONFIRMATION button: Confirm selected preset (RB6);

The program code was developed in object-oriented language C++ in a platform where the code is written (IDE Dev C++) and, from there, passed to the PIC16F690 microcontroller in order to set it as the brain of the pressure simulator invasive arterials. In order for the code to be written in the microcontroller, a small recording equipment that passes these values on to it is necessary. For viewing the code, check it as follows:

```
#include <16F690.h>
#device adc=10 //10 bits
#FUSES NOWDT //No Watch Dog Timer
#FUSES XT //Crystal osc <= 4mhz
#FUSES NOPROTECT //Code not protected from reading
#FUSES NOBROWNOUT //No brownout reset
#FUSES NOMCLR //Master Clear pin used for I/O
#FUSES NOCPD //No EE protection
#FUSES PUT //Power Up Timer
#FUSES NOIESO //Internal External Switch Over mode disabled
#FUSES NOFCMEN //Fail-safe clock monitor disabled
#use fast_io (a)
#use fast_io (b)
#use delay(clock=4000000)
// Definiçoes de projeto
#define rs PIN_A2
#define enable PIN_A1
#define lcd PORTC
#define BT_INC input(PIN_B4)
#define BT_DC input(PIN_B5)
#define BT_CNF input(PIN_B6)
int1 flag_dec=0,flag_inc=1,flag_gera=0;
int recarrega_timer0=10;
long int pic_pos,pic_neg,ciclo=0,value,max=0,min=350,limite=0;
char lcd;
void cfg_lcd(int x){ //função que configura o LCD
      output_low(rs);
      lcd=(x&0xf0);
      output_c(lcd);
      output_high(enable);
      output_low(enable);
      lcd=(x<<4&0xf0);
      output_c(lcd);
      output_high(enable);
      output_low(enable);
      delay_us(50);
}
void putc(char x){//Função para enviar dados ao lcd, chamada pelo printf
      output_high(rs);
      lcd=(x&0xf0);
      output_c(lcd);
      output_high(enable);
      output_low(enable);
      lcd=(x<<4&0xf0);
      output_c(lcd);
      output_high(enable);
      output_low(enable);
      delay_us(50);
}
#int_AD
void AD_isr(void) //função que define os ciclos máximo e mínimo para cada preset
{
      value=read_adc();
      limite=read_adc();
//value=((value*300f)/4.5f)+0.5;

      if(flag_inc)
      if(value==368){ // equivalente a 1,8V na conversão AD
```

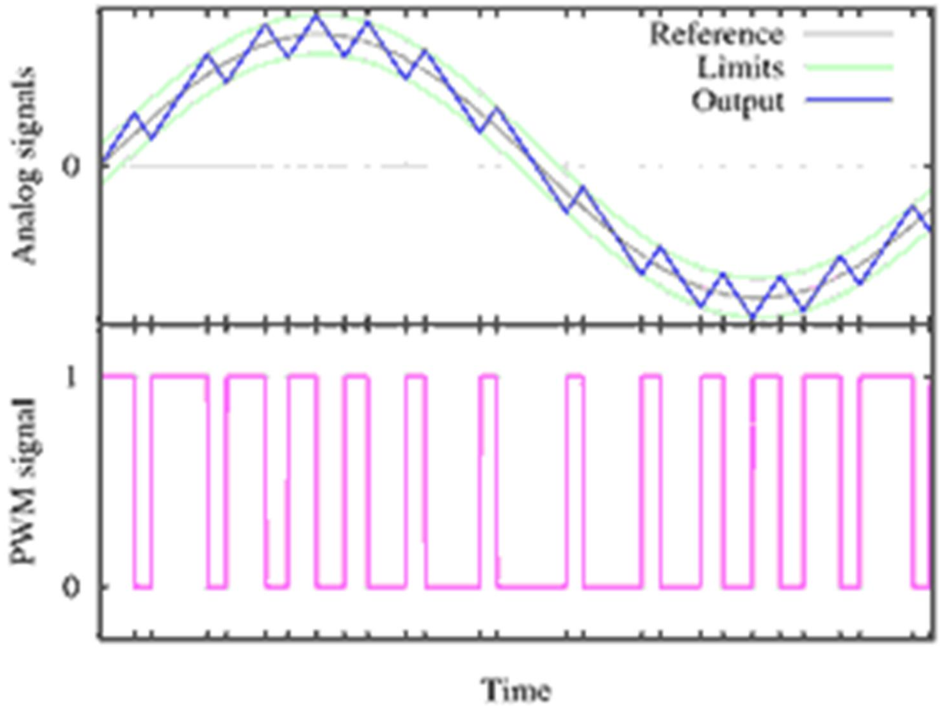
```
      pic_pos=ciclo;
      flag_inc=0;
      flag_dec=1;
}
      if(flag_dec)
      if(value==245){ // equivalente a 1,2V na conversão AD
      pic_neg=ciclo;
      flag_dec=0;
      flag_gera=1;
}
}
#int_TIMER0
void TIMER0_isr(void) //função que incrementa ou decrementa o ciclo a cada
interrupção
{
      set_timer0(get_timer0()+recarrega_timer0);
      if(flag_inc)
      if(ciclo<=pic_pos) ciclo++;
      if(flag_dec)
      if(ciclo>=pic_neg) ciclo--;
}
void main()
{
      int tempo_p;
      setup_spi(SPI_SS_DISABLED);
      setup_timer_1(T1_DISABLED); //desabilita o TMR1
      setup_comparator(NC_NC_NC_NC); //desabilita o modo comparaçao
//TMR0-controle de período
      setup_timer_0(RTCC_INTERNAL|RTCC_DIV_1); //PS 1:1
      enable_interrupts(INT_TIMER0); //TOIE=1
      setup_vref(FALSE);
//AD
      setup_adc_ports(sAN0|VSS_VDD);
      setup_adc(ADC_CLOCK_INTERNAL); //define clock interno para o AD
      enable_interrupts(INT_AD); //ADON=1
//PWM
      setup_timer_2(T2_DIV_BY_16,249,1); //define PR2=249, PS 1:1
      setup_ccp1(CCP_PWM);
      set_pwm1_duty(0); //PWM saida simples, ciclo inicial=0%
      enable_interrupts(GLOBAL); //GIE=1
      recarrega_timer0=10;//Exemplo de tempo
//de cada incremento
//do PWM pós-estabilizado
//os valores do AD
//Aguarda tempo de inicialização do LCD
      delay_ms(150);
//Configurações do LCD
      cfg_lcd(0x28);//Ajusta LCD para 2 linhas com uma matriz de 5x7 (4 bits)

      delay_ms(5);
      cfg_lcd(0x28);
      delay_ms(5);
      cfg_lcd(0x28);
      delay_ms(5);
      cfg_lcd(0x28);
      delay_ms(5);
      cfg_lcd(0x0c);//Display aceso sem cursor
      delay_ms(5);
```

```
    cfg_lcd(0x06);//Escreve deslocando o cursor para a direita
    delay_ms(5);
    cfg_lcd(0x01);//Limpa display e retorna o cursor para o inicio
    delay_ms(5);
    printf(Putc," SIMPRESS II ");
    while(1){
                if(flag_gera==0){//Estabilizando
                set_adc_channel(0);
                for(tempo_p=0;tempo_p<40;tempo_p++);
                read_adc(ADC_START_AND_READ);
                if(flag_inc) //incrementa o ciclo até a leitura do AD ser a
                tensao referente if(limite<=512){ //não pode testar de 1024 a
                0 pois 1024 aplicaria 12V no ++ciclo;
                set_pwm1_duty(ciclo);
                }
                      if(flag_dec) //decrementa o ciclo até a leitura do AD
                      ser a tensao referente if(ciclo>=0){
                            --ciclo;
                            set_pwm1_duty(ciclo);
                      }
                }
                else{//Estabilizado para 1,8v-pic_pos 1,2v-pic_neg
                set_pwm1_duty(ciclo);
                if(ciclo==pic_pos){
                flag_inc=0;
                flag_dec=1;
                }
                else if(ciclo==pic_neg){
                flag_inc=1;
                flag_dec=0;
                }
                }
          }
    }
}
```

The code starts with the declaration of variables, followed by a function that configures the LCD display, which passes to a function of sending data to the LCD, called by printf. Then there is a function that defines the maximum and minimum cycles for each preset, and also a function that increases or decreases the cycle at each interruption. In the main function, initially the microcontroller is configured, the internal clock is defined, that is, the frequency at which it will operate, and the PWM is also configured, that is, the modulation by pulse control. This modulation consists of a strategy to generate sinusoids at the output of the device, which is formed from the increment of a variable over time:

Figure 5 - digital PWM and analog signals.




Source: Portal CitiSystems. Accessed on: Nov. 2021.

By controlling the width of the pulses generated at the output of the microcontroller and then amplified by the power transistor, it is possible to generate a voltage sine wave at the output, with some imperfections due to the small resolution of the microcontroller (the logic to optimize this function is: the greater the number of bits, the greater the resolution).

For implementation in a school, and considering the possibility of cost reduction, the following materials were listed, which can be quoted from an electronic material supplier, who can get them cheaper and possibly from the same supplier:

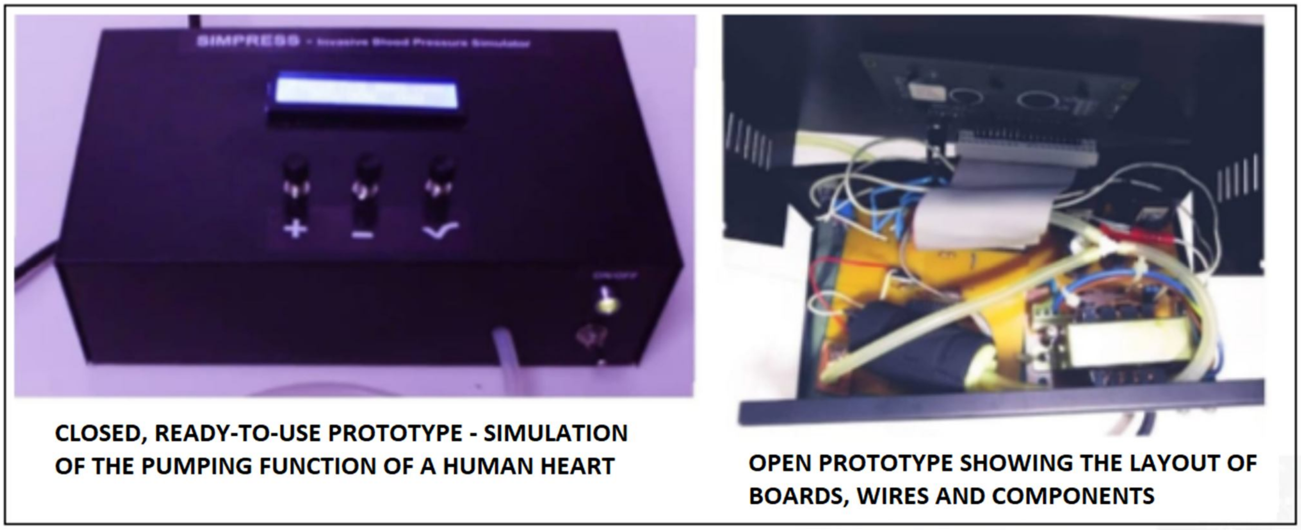
| **Component Name** |
|---|
| 20cm x 11cm x 6cm metallic box |
| 10x10cm Phenolite Plate (1) |
| 10 x 10cm Phenolite Plate (1) |
| 2x15Vac 500mA Transformer (1) |
| 1N Diode 4007 (4) |
| Electrolytic Capacitor 4700uF 25V (2) |
| 12V 7812 Voltage Regulator (1) |
| -12V 7912 Voltage regulator (1) |
| 100nF Polyester Capacitor (6) |

| |
|---|
| Small Panel Fuse Holder (1) |
| 0.1mA 250V glass fuse (1) |
| 110V / 220V 6th switch (1) |
| 250V 3rd rod switch (1) |
| 5mm LED holder (1) |
| 5mm green diffused LED (1) |
| Mains power wire (1) |
| Heatsink 2 TO 220 (2) |
| Connectors and wires |
| 12V 7812 Voltage Regulator (1) |
| 16x2 LCD Display (1) |
| 16-pin bus (1) |
| Resistor 0.25W 150Ω ± 5% (1) |
| Resistor 0.25W 1kΩ ± 5% (1) |
| Resistor 0.25W 220Ω ± 5% (1) |
| Resistor 0.25W 150Ω ± 1% (1) |
| 1N4148 Diode (1) |
| OKEN SEIKO Engine |
| MOSFET IRF840 |
| Stamped CI 20-pin socket (1) |
| Stamped 8-pin CI socket (1) |
| 16F690 Microcontroller (1) |
| AD620 Instrumentation Amplifier (1) |
| Pressure Sensor MPX2300DT1 |
| 50cm silicone hose |
| TL084 |
| TIP 122 |
| 1800 PX cable (1) |
| Edwards TruWave Pressure Transducer (1) |

Table 1 – List of components used. Source: the author (2021).

With this information from the list of components, it is possible to acquire them in larger quantities so that different groups of students can develop the prototype, which can be thought of in the form of interdisciplinary projects in various disciplines, involving multiple teachers in carrying out this project.

Figure 6 – Technology presentation inside a metal box.




Source: the authors (2021).

## Final considerations

We considered the prototype of a simulator of invasive blood pressure as well as a simulator of a part of the human heart functioning, a device that can allow a learning experience with the contribution of different areas, such as electronics, robotics, anatomy, physiology, among others. Also, we see the possibility in contributing to skills in interpersonal communication, oral presentation of projects and its results.

On the other hand, this prototype can be used in different scholar contexts and also it can be improved for technical use in hospitals, such as the checking and maintenance of IBP equipment. Thus, in addition to being a technological pedagogical tool, the project can be a way for students to think about the possibility of solving broader problems that include the clinical engineering scenario in their country.

In addition, considering the importance of technological literacy that is essential in emerging countries, as a way to promote social inclusion. Our prototype which involves both electronic design and program/software coding allows students to engage in the STEM area and advance in direction to acquire multidisciplinary knowledge in their training. Finally, the development of hand skills is also promoted once the handling of the prototype components since the building process of the circuit plates, the physical system and other activities.

Furthermore, our prototype is a proposal for teachers that aim to engage their students in activities involving living organisms with ethical issues and also contribute to technological literacy. The implementation of the prototype in different classes is the aim of future research.

## BIBLIOGRAPHIC REFERENCES

CARRARETTO, Antonio Roberto. **Propriedades e Diferenças entre: Transdutores de Pressão.** Espírito Santo: Medicina Perioperatória. Disponível em: <http://www.saj.med.br/uploaded/File/artigos/Propriedades%20e%20diferencas%20%20transdutores%20de%20pressao.pdf>. Acessado em: 29 maio 2010.

GHIRARDELL, Ariovaldo. **Apostila Sobre Modulação PWM.** Disponível em: <http://www.eletronica.org/arq_apostilas?apostila_pwm.pdf>. Acessado em: 13 mar. 2011.

LIMA FILHO, D. L.; QUELUZ, G. L. . A tecnologia e a educação tecnológica: elementos para uma sistematização conceitual. **Educação & Tecnologia,** Belo Horizonte, v. 10, n.N. 1, p. 19-28, 2005.

MITUSHIMA, Simone Mattoso. **O cateter.** São Paulo: Universidade Federal de São Paulo (UNIFESP). Disponível em: <http://www.unifesp.br/denf/NIEn/hemodinamica/pag/cateter.htm>. Acessado em: 28 maio 2010.

SILVA, A. C. Educação e tecnologia: entre o discurso e a prática. **Ensaio (Fundação Cesgranrio. Impresso),** v. 19, p. 527-554, 2011.

Oliveira, C.S., P.A. Nogara, G.L. Schmitz and J.B.T. Rocha,. 2017. “Insulin as a model to teach three-dimensional structure of proteins.” *Journal of Biochemistry Education,* 15(2), 114-130.

Paiva, M.R.F., J.R.F. Parente, I.R. Brandão, and A.H.B. Queiroz. 2016. “Metodologias ativas de ensino-aprendizagem: Revisão integrativa.” *Sanare, Sobral*, 15, 145-153.

Schmitz, G.L., P.A. Nogara, N. Medina, J.B.T. Rocha, N.V. Barbosa, A.L.A. Segatto and C.S. Oliveira. 2020. “Cockroaches: an alternative model to teach enzymatic inhibition to undergraduate students.” *Journal of Biological Education,* doi: 10.1080/00219266.2020.1808512

Whitaker, R. H. (2010). *Anatomy of the heart. Medicine, 38(7), 333–335.* doi:10.1016/j.mpmed.2010.04.005

Loukas M, Bilinsky S, Bilinsky E, et al. Cardiac veins: a review of the literature. Clin Anat 2009; 22: 129e45.

COWLEY Jr, A.W. Long-term control of arterial blood pressure. Physiological Reviews. 1992, 72(1), 231-300. doi: 10.1152/physrev.1992.72.1.231

RIBEIRO, M.M. Letramento Digital. Trabalho de conclusão de curso (Curso de Tecnologia em Processamento de dados) - Faculdade de Tecnologia de Americana, Americana, 2008.

BRASIL. Base Nacional Comum Curricular (BNCC). Educação é a base. Brasília. MEC/CONSED/UNDIME, 2017.

BYBEE, R.W. 2010. The teaching of science : 21st-century perspectives. National Science Teachers Association - NSTA Press. 225p.