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Senior Design Project Report

Design of Experiments to study the enhancement of heat transfer rate of vehicle radiator using Nano fluid

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

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Abstract

Heat exchangers play an important part in the field of energy conservation, conversion and recovery. Numerous studies have focused on direct transfer type heat exchanger, where heat transfer between fluids occurs through a separating wall or into and out of a wall in a transient manner. There are two important phenomena happening in a heat exchanger: fluid flow in channels and heat transfer between fluids and channel walls. Thus, improvements to heat exchangers can be achieved by improving the processes occurring during those phenomena. Nanofluids, on the other hand, display much superior heat transfer characteristics compared to traditional heat transfer fluids. Nanofluids refer to engineered fluids that contain suspended nanoparticles with average size below 100nm in traditional heat transfer fluids such as water, oil and ethylene glycol.

An experimental system will be designed and constructed to investigate heat transfer behavior of different type of nanofluid a car-radiator heat exchanger. Heat transfer characteristics will be measured under the turbulent flow condition. The experiments is planned to be conducted for wide ranges of Peclet numbers, and volume concentrations of suspended nanoparticles. The outcome expectation is to measure the significance of Peclet number on the heat transfer characteristics. The optimum volume concentrations in which the heat transfer characteristics become the maximum enhancement is also addressed. Finally, the structure of different nanofluid is compared.

Acknowledgments

First of all we would like to thank “Allah” for everything. Then, we would like to thank our families and friends for all the support and inspiration that they have provided to us. After that we would like to thank the Prince Mohammed Bin Fahad University and the mechanical engineering department and all the professors and instructors who provided us with all the required knowledge and skills to be a successful leaders in the coming future. We would like to thank and show our deep appreciation to Dr. Nader Sawalhi, Dr. Essam Jasim and Dr. Faramz dajvanroodi for their guidance and valuable assistance, advising us through the whole project period. They were always there for us to answer all our questions.

List of Acronyms (Symbols) used in the report:

L	Length
V	Volume
T	Temperature
ρ	Density
$\dot{m}_c$	Mass flow rate for air
$\dot{m}_h$	Mass flow rate for fluid (water)
c_p	Specific heat
$\dot{Q}_{max}$	Heat rate
$\in$	Effectiveness
ΔP	Pressure drop
f	Friction

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CHAPTER 1

Chapter 1: Introduction

1.1 Project Definition

It is theoretically approved that using Nano particles would improve the performance of the heat transfer. This project is to investigate the concept of using nanofluid in heat exchangers experimentally.

Nanofluids are engineered colloids made of a base fluid and nanoparticles (1-100 nm). Nanofluids have higher thermal conductivity and single-phase heat transfer coefficients than their base fluids. The concept of Nanofluids refers to a new kind of heat transport fluids by suspending Nano scaled metallic or nonmetallic particles in base fluids. Energy transport of the Nano fluid is affected by the properties and dimension of nanoparticles as well as the solid volume fraction.

The convective heat transfer coefficient of the nanofluid increases with the flow velocity as well as the volume fraction of nanoparticles and it is larger than that of the base liquid water under the same flow velocity. In some cases, the viscosity of the dispersed fluid sharply increases with increasing the particle volume fraction and becomes much higher than that of the base liquid, so that higher volume fraction of the solid particles may suppress heat transfer enhancement of the suspension.

One of difficulties in this experiment is the controlling of the Nano particles flow within the water layers in the heat exchanger tube. However, this problem can be overcome by using ultra sounds waves. In addition, according to Yimin.X "The relationship between the amount of Nano particles in the water flow and the heat transfer efficiency is directly proportional until it reaches the breaking point which gives then an opposite relationship" so we have to do optimization between these two parameters during the experiment. Also, some well-performance Nano particles cause corrosion in the tubes which makes us to find a solution for that and trying another kind of Nano particle to compare between them.

1.2 Project Objectives

Objective1: Setting up the experiment equipment.

This project will involve the suspension of Nano particles in a fluid, and having it heated and passed through a radiator. This process will be accomplished with the use of a household water heater, pipes, car radiator, fan, and ultrasound attachments. A temperature and pressure gauges will be placed before and after the fluid enters the radiator, which will insure the accuracy of our results.

The water heater will be set to a temperature of 30 degrees C. The temperature and pressure will be monitored before entering the Radiator, and after exiting. This will allow us to compare the efficiency of the system on more than one criterion.

The Nano particles will be suspended using ultrasound devices placed in various places to insure that the Nano particles do not precipitate. The design of the piping will also be in a way that causes the least chance for precipitation or blockages.

Objective2: Doing the experiment to investigate the concept of Nano fluid in heat exchangers.

We are attempting to practically prove what has already been done theoretically, which is that Nano fluids would increase the efficiency of a system with a slight or no pressure drop. This would mean that Nano fluids could be used in industrial settings to increase the efficiency of the systems for nominal costs. Since our project is short term we will not take into account the possibility of corrosion.

Objective 3: Optimizing the results and Comparison between the experimental and theoretical results.

Our research indicates that there is a threshold ratio after which the increase in the volume of Nano particles would hinder the system. Our research show us that the limit is near 20% Nano to fluid volume ratio, and after that there may be pressure drop, increase friction, or other factors that compromise the system.

1.3 Applications

This project is a continuance of all the other theoretical studies that have been done on the subject. We are experimentally proving that Nano particles in fluids would enhance efficiency without compromising pressure. This would mean that the technology would be a step closer to being used in industrial settings.

The major application of this project is in industrial heat transfer settings such as power plants, desalination plants, and maybe even in the Radiators of trucks.

The project is meant to increase the efficiency of current systems without significant investment, and reduce the cost of future systems by increasing the efficiency of smaller parts to do the job.

CHAPTER 2

Chapter 2: Literature Review

2.1 Project background

Fluids are often used as heat carriers in heat transfer equipment. With its various applications, the thermal conductivity of heat transfer fluids plays a vital role in the development of energy-efficient heat transfer equipment. With an increasing global competition, industries have a strong need to develop advanced heat transfer fluids with significantly higher thermal conductivities than are presently available (Stephen, Choi and Eastman, 1995). The more used fluids such as water, the ethylene glycol and oil possess a relatively weak thermal conductivity, as shown in table (2-1). New ways of optimization consist in using new fluids named "Nanofluids" capable of improving the thermal transfers. The nanofluids are colloidal solutions composed of metallic particles of nanometric size in suspension in a base liquid (Thierry & others, 2011).

Table (2-1): thermal conductivities (W/m-K) of various materials, (Stephen, Choi and Eastman, 1995).

Material	Thermal conductivity
Copper	401
Aluminum	237
Silicon	148
Sodium® 644 K	72.3
Water	0.613
Engine oil	0.145

The idea of using metallic particles to increase the thermal conductivity of fluids is not a new concept. By knowing the fact that metals in solid form have much higher thermal conductivity than fluids, Maxwell (1873) who was the one originally proposed the idea of using metallic particles to increase the thermal properties of fluids. This was followed by many trials by dispersing millimeter and micrometer sized particles in liquids. However, these large particles had several problems such as particle sedimentation, passage clogging, erosion and high-pressure drop. The recent development of nanotechnology, however, opened up the opportunity to revisit Maxwell’s idea by using nanometer (one billionth of a meter) sized particles (Mohammed & others, 2011).

Compared with the existing techniques for enhancing heat transfer by adding millimeter and/or micrometer-sized particles in fluids, nanofluids are expected to be ideally suited for practical application with incurring little or no penalty in pressure drop because the nanoparticles are so small that the nanofluid behaves like a pure fluid. It is expected that the main reasons of heat transfer enhancement of the nanofluids may be from intensification of turbulence or eddy, suppression or interruption of the boundary layer as well as dispersion or back-mixing of the suspended nanoparticles, besides substantial augmentation of the thermal conductivity and the heat capacity of the fluid. Therefore, the convective heat transfer coefficient of the nanofluids is a function of properties, dimension and volume fraction of suspended nanoparticles as well as the flow velocity, see figure (2-1) (Xuan & Li, 2008).

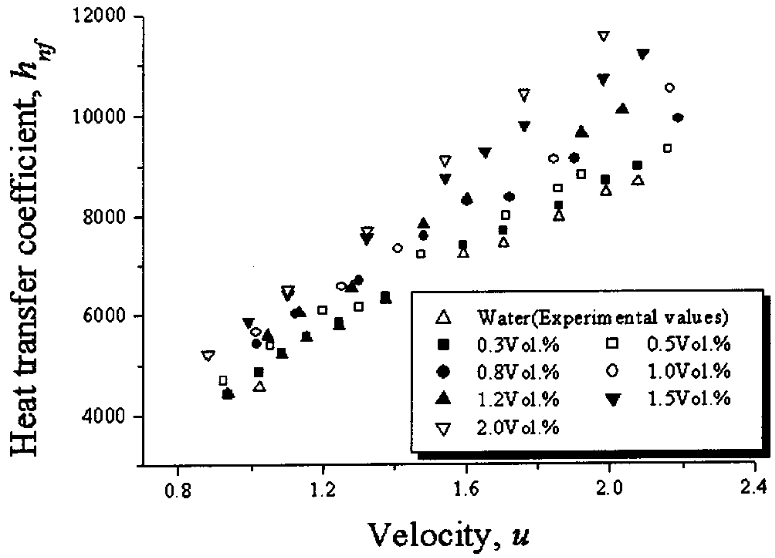


Figure (2-1): Variation of heat transfer coefficient with velocity in the turbulent flow, (Xuan & Li, 2008).

2.2 Previous Work

In a study done by Stephen, Choi and Eastman, the feasibility of the concept of high-thermal-conductivity nanofluids has been demonstrated by applying the Hamilton and Crosser (1962) model to copper nanoparticles in water, together with some experimental results of Masuda, et al. (1993) for y-Al203 particles in water. One of the benefits of the nanofluids will be dramatic reductions in heat exchanger pumping power, see figure (2-2). For example, to improve the heat transfer by a factor of 2, the pumping power with conventional fluids should be increased by a factor of 10. However, if a nanoparticle-based fluid with a thermal conductivity of =3 times that of a conventional fluid were used in the same heat transfer equipment, the nanoparticle-based fluid would double the rate of heat transfer without an increase in pumping power (Stephen, Choi and Eastman, 1995).

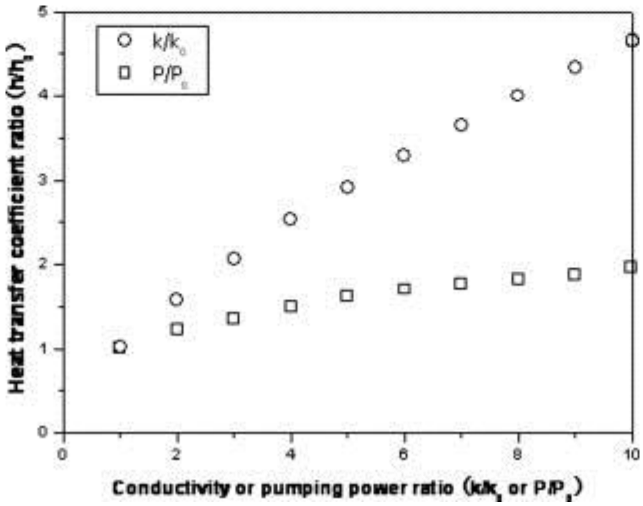


Figure (2-2): Effects of thermal conductivity and pumping power on heat transfer (Journal of Heat Transfer, n.d.).

Investigating the convective heat transfer of nanofluids in a tube, Xuan and Li reported that, the suspended nanoparticles remarkably enhance heat transfer process and the nanofluid has larger heat transfer coefficient than that of the original base fluid under the same Reynolds number. The heat transfer rate of a nanofluid increases with the volume fraction of nanoparticles. By considering the micro-convection effects of the suspended nanoparticles, a new type of the convective heat transfer correlation for nanofluids in a tube has been proposed, taking the main factors of affecting heat transfer of the nanofluid into account. On the other hand, the friction factor for the dilute nanofluids consisting of water and Cu-nanoparticles is approximately the same as that of water. The nanofluid with the low volume fraction of the suspended nanoparticles incurs almost no extra penalty of pump power (Xuan & Li, 2008).

Studying the thermal performance of nanofluids in a plate heat exchanger, Thierry & others reported that, the results have shown an improvement in laminar mode of the convective heat transfer coefficient of about 42% and 50% for (γAl_2O_3) and (CNTs) respectively compared to that of pure water for the same Reynolds number. The results have also shown that the impact of the viscosity and the pressure drop at low temperatures is important and has to be taken into account before to use nanofluids in heat exchanger. Finally, it had been observed that the thermal losses can reach 22% for (γAl_2O_3) and 150% for (CNTs). This result reports that alumina and Carbone nanotubes show a better thermal-hydraulic performance in terms of a competition between heat transfer enhancement and pumping power loss in comparison with pure water (Thierry & others, 2011).

According to a research done by Etemad & Farajollahi, an experimental system was designed and constructed to investigate heat transfer behavior of γ-Al2O3 nanofluid in a shell and tube heat exchanger, see figure (2-3). Heat transfer characteristics were measured under the turbulent flow condition. The experiments were done for wide ranges of Peclet numbers, and volume concentrations of suspended nanoparticles. Based on the results, the heat transfer characteristics of nanofluids improve with Peclet number significantly. Addition of nano-particles to the base fluid causes the significant enhancement of heat transfer characteristics and results in larger heat transfer coefficient than that of the base fluid at the same Peclet number. The nanofluid has an optimum volume concentration in which the heat transfer characteristics show the maximum enhancement.

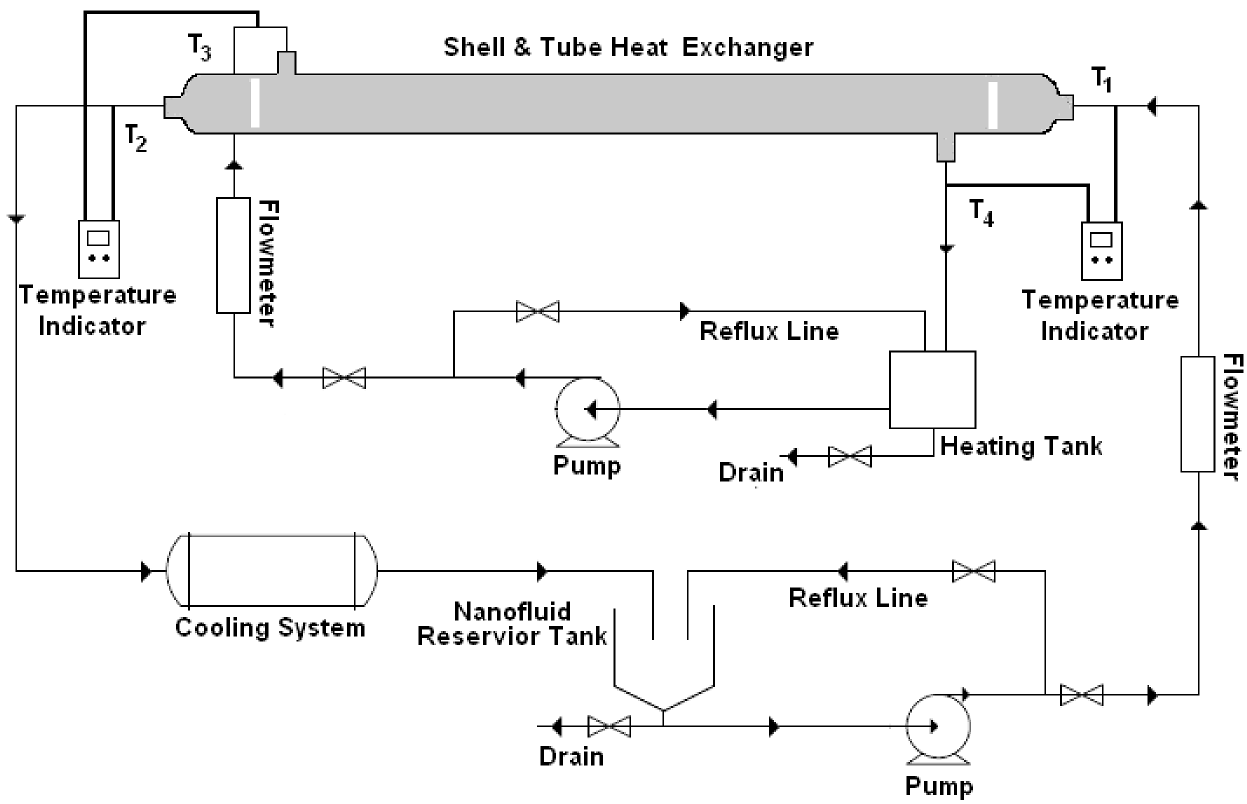


Figure (2-3): experiment setup of shell and tube heat exchanger, (Etemad and Farajollahi, n.d.).

2.3 Comparative Study

To apply the nanofluid to practical heat transfer processes, more studies on its flow and heat transfer feature are needed. Pak and Cho performed experiments on turbulent friction and heat transfer behaviors of two kinds of the nanofluids. In their study, g-Al2O3 and TiO2 were dispersed in water, and the experimental results showed that the Nusselt number of the dispersed fluids increases with increasing the volume fraction of the suspended solid particles and the Reynolds number. Lee and Choi applied the nanofluid as the coolant to a microchannel heat exchanger for cooling crystal silicon mirrors used in high-intensity X-ray sources and pointed out that the nanofluid dramatically enhances heat transfer (Xuan & Li, 2008).

In fact, numerous theoretical and experimental studies of the effective thermal conductivity of dispersions that contain solid particles have been conducted since Maxwell's theoretical work was published more than 100 years ago, (Maxwell, 1881). However, all of the studies on thermal conductivity of suspensions have been confined to millimeter- or micrometer-sized particles. Maxwell's model shows that the effective thermal conductivity of suspensions that contain spherical particles increases with the volume fraction of the solid particles. It is also known that the thermal conductivity of suspensions increases with the ratio of the surface area to volume of the particle (Stephen, Choi and Eastman, 1995).

There are few published studies on the forced convective heat transfer coefficient of nanofluids and most of them are under the constant heat flux or constant temperature boundary conditions at wall of tubes and channels. In shell and tube heat exchangers the real heat boundary condition is different from the aforementioned boundary conditions and wall temperature and/or heat flux is not constant in heat exchangers. The available experimental results in the literature show that the convective heat transfer coefficient of nanofluids can be enhanced compared to base fluid (Etemad & Farajollahi, n.d.)

An experimental system will be designed and constructed to investigate heat transfer behavior of different type to nanofluids in a car radiator heat exchanger. Heat characteristics will be measured under the turbulent flow condition. The experiment is planned to be for wide ranges of Peclet numbers, and volume concentration of suspended nanoparticles. The outcome expectation is to measure the significance of Peclet number on the heat transfer characteristics. The optimum volume concentration in which heat transfer characteristics become the maximum enhancement is also addressed. Finally, the structure of different nanofluid is compared.

CHAPTER 3

Chapter 3: System Design

3.1 Design Constraints

Since our project is mainly about setting up an experiment to investigate a theory that concluded, “heat transfer rate can be enhanced with using nanoparticles flowing through the fluid layers”, our concern is about how to setup an experiment in a way that gives reliable results. In other words, we will consider the possible sources of errors and how to be prevented or limited.

One of main problems is controlling the flow of the nanoparticles that we have to overcome as illustrated in the next chapter. In addition, the relationship between the amount of nanoparticles in the water flow and heat transfer efficiency is directly proportional, however, its behavior reverse at a specific point “breaking point”, and the pressure drop is inversely proportional with the heat transfer efficiency, [1]. Accordingly optimization between these parameters should be conducted, meaning to reach the highest possible efficiency with the least possible pressure drop.

Moreover, as engineers we consider engineering standards, environmental, economic, manufacturing, and safety issues. As a result, we have taken into consideration the engineering standards for parts and equipment selection. The main equipment in our prototype are a fan, car radiator, electric water pump, heater, and a water container, in addition to the tubes, valves, pressure gage, and temperature sensors. Most of the parts and some of the equipment are locally made following the SASO standards. The car radiator, the fan, and the water pump we have used are South Korean made, which follows the national standard KATS (The Korean Agency for Technology and Standards), [2].

Environmentally speaking, the prototype design has no serious issues**.** There are no harm exhausts or plenty of water used since we planned to use the least possible water to reach our goals. In addition, we opened an additional outlet in the water container for water discharge and we used a container for the waste discharged water that including nanoparticles to keep the area dry and clean.

The **manufacturability** of this prototype was not complicated at all. There was some manufacturing on the water container to make holes for the inlet, outlet, discharge tubes, and install water heater, figure (3.1). Also, we made frames of wood to fix the fan and radiator on the table, figure (3.2).

Figure (3.1) the manufacturing work done in the water container

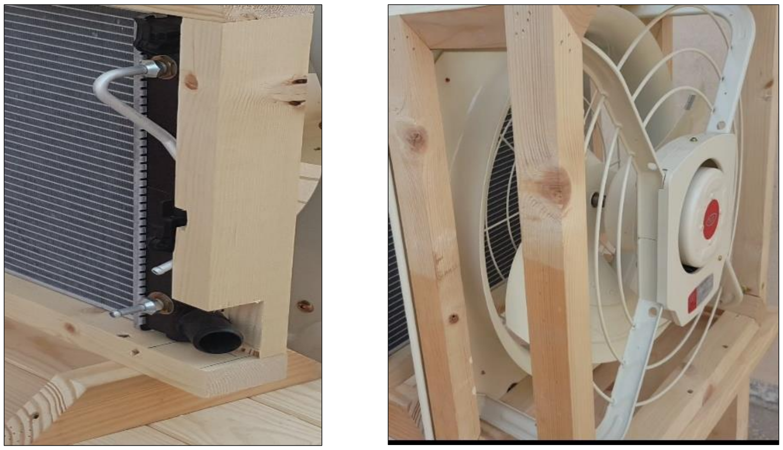


Figure (3.2) Frames for the radiator and fan to fix them on the table.

Safety was highly taken into consideration. We have bought equipment with high quality standards. Each of the fan, water pump, and heater are electric equipment so we had to find some expert technicians for wiring them with an efficient and safe wires and cables, figure (3.3). Moreover, we have put warning signs around the fan frame, for anyone passing by, not to touch it when it is switched on.

Figure (3.3) Electrical cable and wires

3.2 Design Methodology and Theoretical Calculations

Figure (3.4) illustrates the project architecture. It shows the function of the system with the devices and the way the whole system operate. The approach of the system design started with finding a heat exchanger and we chose a car radiator with a fan. However, the water pump used in cars are mechanical (it connects to the engine) which cannot be properly worked in the experiment. This caused us to try an electrical pump with features that illustrated in section 3.3. In addition, we planned to use woody frames for the fan and heat exchanger to fix them on the table. We need to find the best quality places with the minimum prices (to control our budget) to do the frames and the table. After choosing the proper parts and devices, we used SolidWorks software in order to simulate the assembly of the system. Last but not the least, we must assemble the components of the experiment in the way we instructed by the advisor with the consideration of previous works. Finally, we will do several experiment with and without using nanoparticles and publish our results and recommendations we observed.

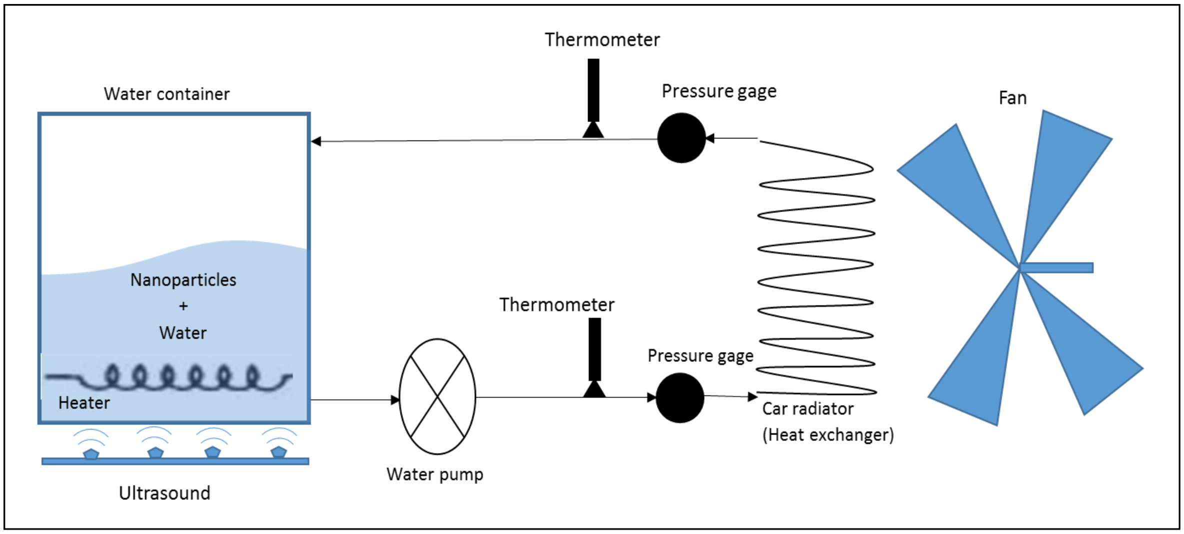


Figure (3.4) project architecture diagram

3.2.2 SolidWorks

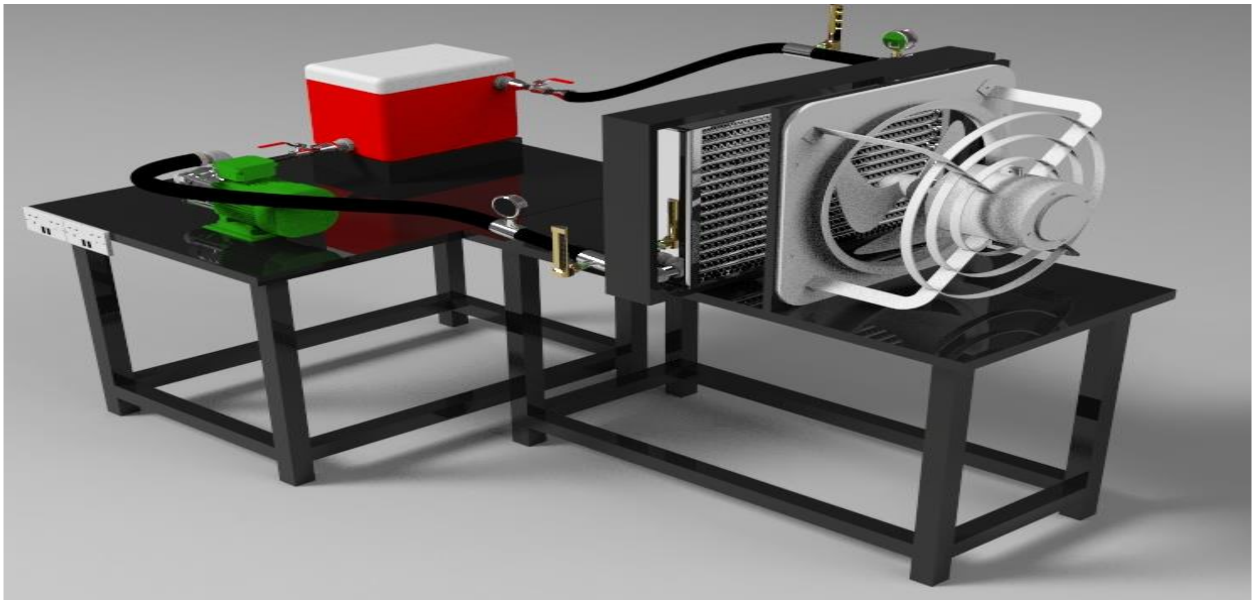


Figure (3.5), side view of the design of the experimental set up

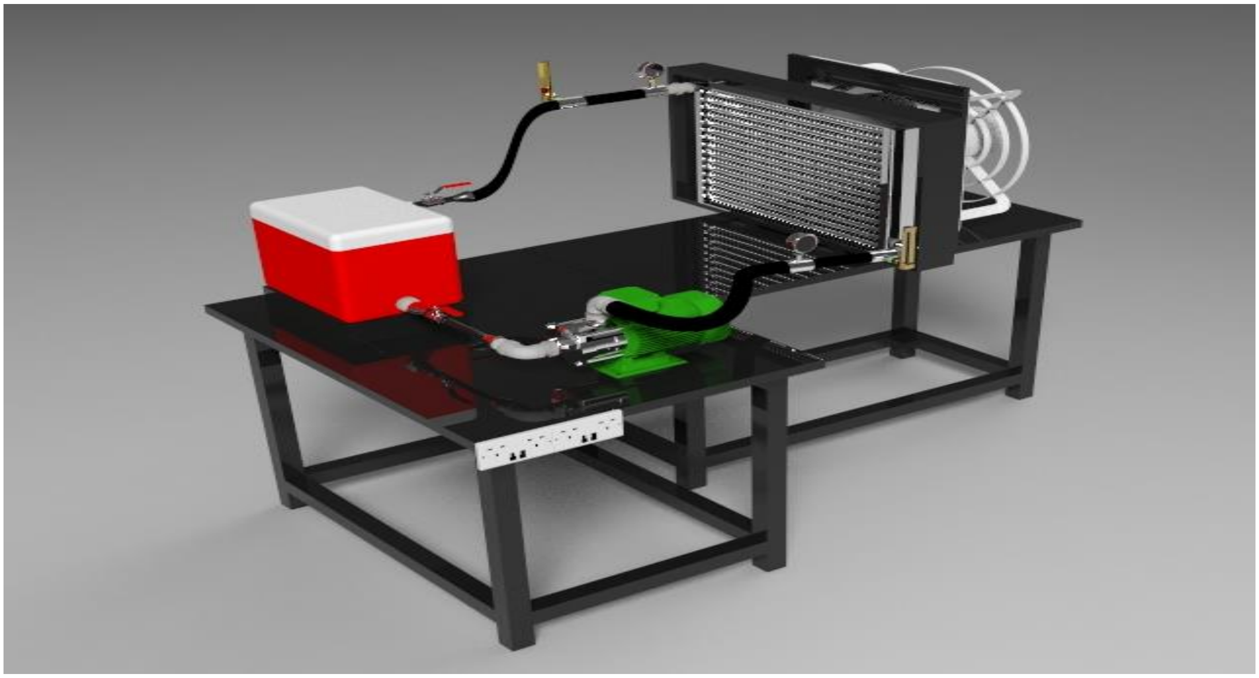
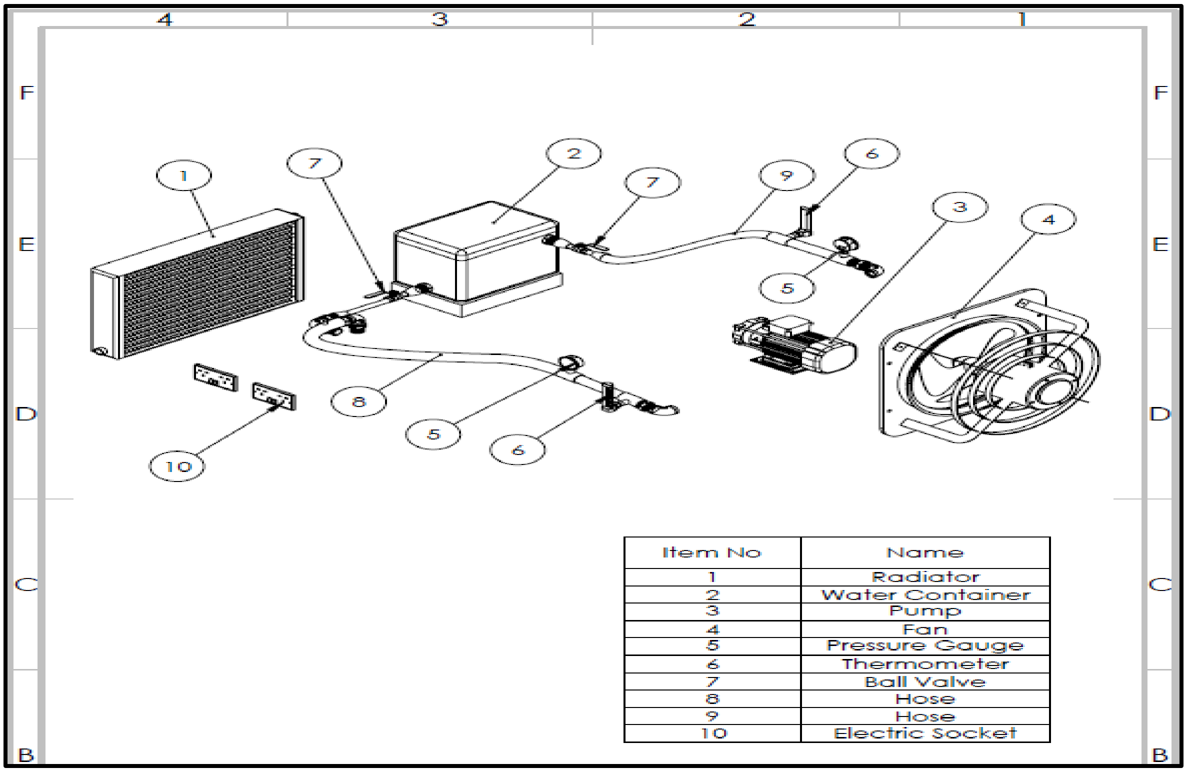


Figure (3.6), another side view of the design of the experimental set up



Item No	Name
1	Radiator
2	Water Container
3	Pump
4	Fan
5	Pressure Gauge
6	Thermometer
7	Ball Valve
8	Hose
9	Hose
10	Electric Socket

Figure (3.7), Exploded view of the design of the experimental set up

3.2.2 Equations used in the calculation.

The values listed in the chapter four tables were obtained from the following equations.

$$C_c = \dot{m}_c c_p$$

$$C_h = \dot{m}_h c_p$$

$$\dot{Q}_{air} = C_c(T_{in} - T_{out})$$

$$\dot{Q}_{water} = C_h(T_{in} - T_{out})$$

$$\dot{Q}_{max} = C_{min}(T_{h,in} - T_{c,in})$$

$\in = \frac{Q_{air}}{Q_{water}}$ **Or** $\in = \frac{Q_{water}}{Q_{air}}$ (the greater value is in the denominator) equation (3.1)

$$Q_{actual} = Q_{max} \in$$

$$Q_{actual} = UA_s \Delta T_{lm}$$

$$\Delta T_{lm} = F \Delta T_{lm,CF}$$

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)}$$

$$\Delta T_1 = T_{h,in} - T_{c,out}$$

$$\Delta T_2 = T_{h,out} - T_{c,in}$$

$$\Delta P = f . \frac{L}{D} \frac{V^2}{2} \rho$$

$$V = \sqrt{\frac{4\dot{m}}{\pi D^2}} \quad , \quad D = \frac{4ab}{2(a+b)}$$

3.3 System and Components:

Our design for short is a project that can be used to transfer heat from hot water in a heat exchanger to Nano-fluid and make temperature calibrations for the same by using two thermo-couples in the cycle. The complete system includes flow meters will be fitted in the pipes and carrying Nano-fluid to check its flowing rate as it shown in figure (3.7).

Figure (3.8): Structural System

After the required specifications and sizing are enlisted, we searched in the market and available auto parts which matching our components. All the components are available and fit together perfectly. Here are the components and the alternatives found:

- The shell and tube heat exchanger is of stainless steel type 316 L, 248 mm long consisting of 37 tubes.
- The two flow loops available in the market are 2.2 mm used in auto air-condition systems and they are so chosen for their size matching.
- A heating unit is also a household water heater because its outlets fit in the thermo controller unit.
- For the tanks we used Household water size 20-liter.
- Two thermometer to measurement temperature units of inlet and outlet
- One pump (GP/05HPN1 S6) was selected because they are available and their outlets exactly match the flow loop diameter and also the flow meter.

3.3.1 Radiator:

The shell & tube heat exchanger was the component that we found hard time providing. After long search we found the smallest industrial use shell & tube heat exchanger of stainless steel type 100 L, 158 mm long consisting of 37 tubes. The tube diameter is 2.2 mm with a tube wall thickness of 0.19 mm, and area of 0.05 m^2 as shown in figure (3.8).

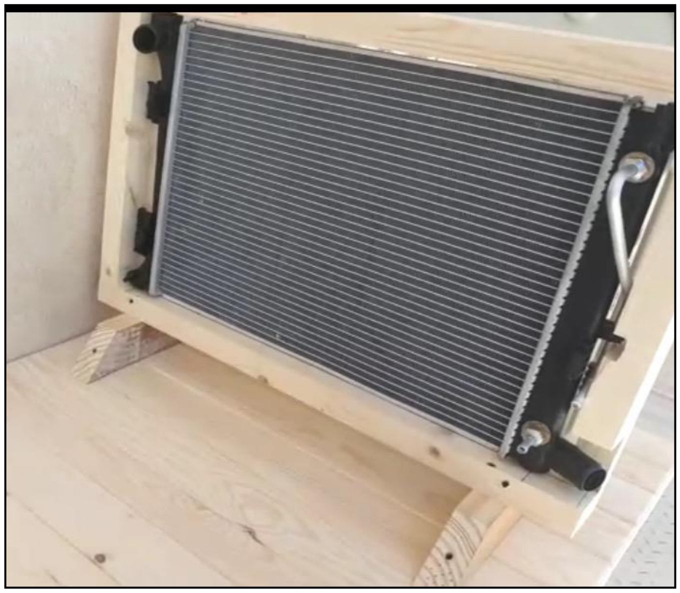


Figure (3.9): Shell & tube heat exchanger

3.3.2 Plumping system:

The flow loops are two thermo-couples tubes with removable bulbs which are inserted on the heat exchanger to measure the bulk temperatures of inlet and outlet fluid streams. Suction pipe 1 inch. The pipes are used with maximum capacity 44 (L/min), and total heat head max 38 (m) as illustrated in the figure (3.9).

Figure (3.10): Pipe

3.3.3 Water pump:

The pump we used was purchased locally, and its specifications as shown in table (3.1) and figure (3.11) out performs the other available pumps. The pump as illustrated in figure (3.10) was also reasonable for its performance and its quality. The pumps we used before either broke down or couldn't give us the required pumping power.

Figure (3.11): Peripheral water pump.

Table (3.1) PUMP FEATURES:

Q 5 - 44 L/min	H 38 - 5m	
H_{max} 40m	H_{min} 5m	$T_{liquid\ max}$ 60 C
V~220	Hz 60	Phase 1
P2 0.37 kW	HP 0.5	Min^{-1} 3510
P1 0.59kW	In 2.7A	I. Class F
mF 8	Vc 450V	IP 54
Continuous running duty S1		

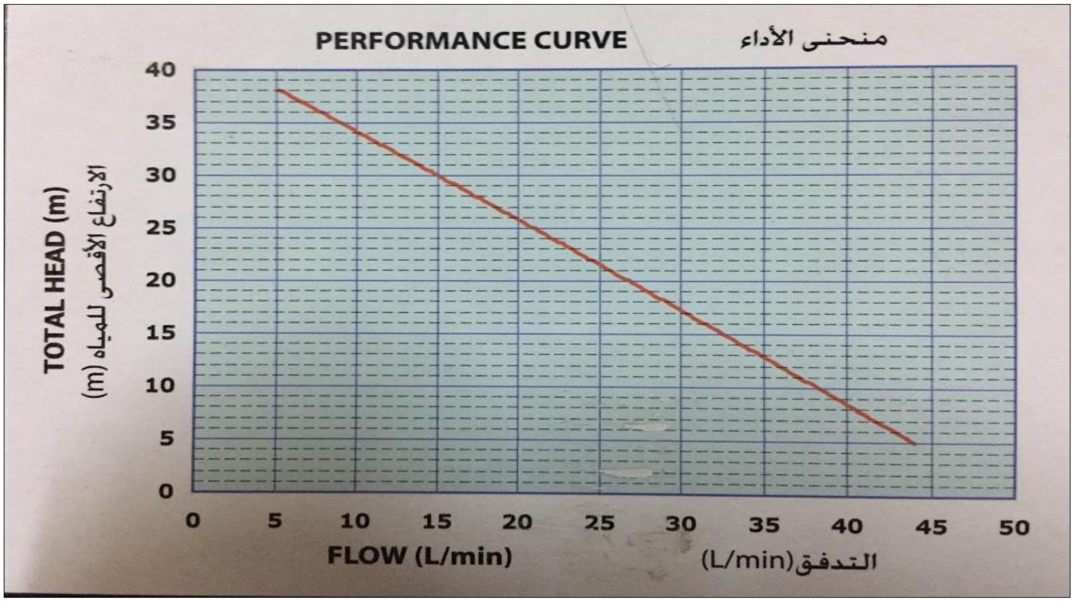


Figure (3. 12): Pump performance curve

3.3.4 Fan:

A 220V fan has been used as shown in figure (3.12) and air flow power is approximately 116.7 m/min to enhance more power to cool down water inside the radiator. And for more specifications and features, shown in table (3.2).

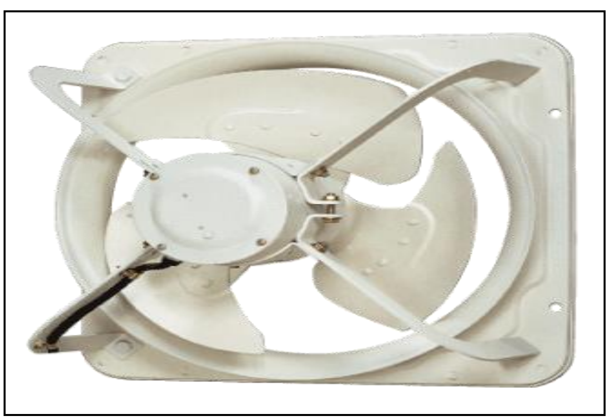


Figure (3.13): Cooling Fan

Table (3.2) Fan features:

POWER	1 θ 220V 60Hz	**POLES**	4 P
INPUT	435 W	**AIR FLOW**	116.7 m^3/min
INSULATION	E CLASS	**IMPELLER**	45 cm
WEIGHT	16 kg		

3.3.5 Instrumentation system:

Our instrument included several gauges namely: temperature controller “thermometer” shown in figure (3.13) and pressure gauges figure (3.14). The availability and the reading ranges of the instruments were all selected based on the specific specifications.

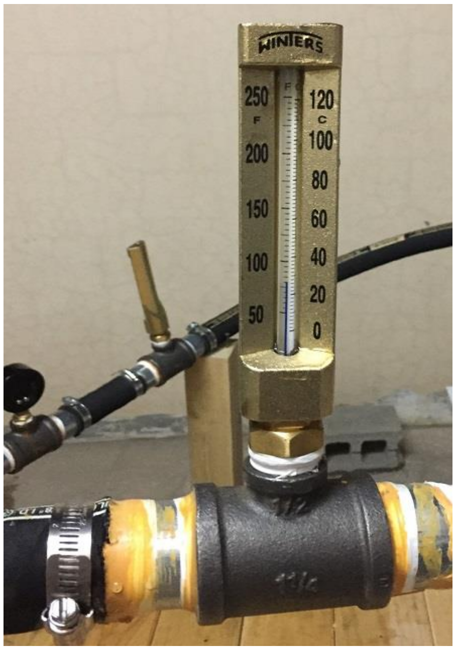


Figure (3.14): Thermometer

Figure (3.15): Pressure gauges

3.3.6 Fluid:

- Aluminum Oxide (Al_2O_3) Nano powder / Nanoparticles Dispersion (Al_2O_3 Nanoparticles Aqueous Dispersion, Alpha, 20wt%, 30nm) ”120ml/120g”, figure (3.15).

- Copper Nanoparticles / Nano powder (Cu Nanoparticles with 5.2wt% Cu_2O coated, 30 nm) “100g”, figure (3.16).

Figure (3.16): Aluminum Oxide

Figure (3.17): Copper Nanoparticles

3.3.7 Electronic scale:

As illustrated in the figure (3.17), we have used an electronic scale to measure the Nano particles. It has been used to know the weight of Nano particles before being in the water.

Figure (3.18): Electronic scale

3.3.8 Ultra sound:

As shown in figure (3.18), we have utilized the ultra sound technology and it has been programed and used 9 pieces to place under the container to prevent nano accumulation inside it.

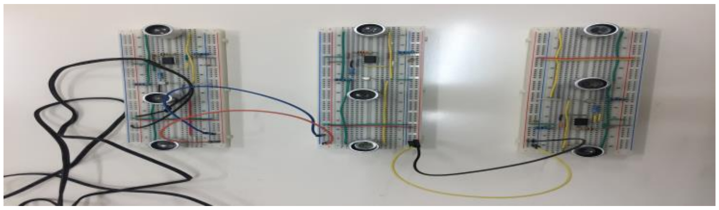


Figure (3.19): Ultra sound

3.4 Implementation

Since the beginning of the project we took into consideration that it is really important to understand our main task of the project to be able to work in consistence way, for instance the project design, cost, parts, assembly and ordering the nanoparticles must be available at its function time. As shown in table 3.3 the project main task and its description are explained.

Table (3.3): the project main tasks and its description

Main tasks	Description
Project design	Solid Works used to draw our design.
Cost	We searched on the internet and visited some local stores to know the prices before buying.
Purchasing parts	After knowing the prices and costs, we bought high quality parts with good prices.
Virtual design	After collecting all parts we redesign our completed system using Solid Works.
Assembly	In the spring break we assembled our system and using expert technicians for electrical wiring
Nano-particles	We ordered two types of nano-particles from the trusted website.

CHAPTER 4

4.1 System testing:

Objective: to investigate heat transfer behavior of different type of nanofluid in a car-radiator heat exchanger. Heat transfer characteristics will be measured under the turbulent flow conditions. In addition, the optimum volume concentrations in which the heat transfer characteristics become the maximum enhancement is addressed and also the performance of the two nanoparticles is compared.

Setup: All parts of the system has been connected in a way that it would ensure accurate and precise results. We place the water heater and radiator on the same level using wooden tables, and linked them by piping system with water pump to provide more velocity. A temperature and a pressure gauge were placed at inlet and outlet of the radiator to calculate the heat transfer and pressure drop. Finally, an ultra sound device was used at the bottom of the water heater to allow smooth flow for the nanoparticles within the water.

4.2: Overall results, analysis and discussion

Table (4.1): observed data for a pure water with no Nano particles

$T_{in,air}$ ℃	$T_{out,air}$ ℃	$T_{in,w}$ ℃	$T_{out,w}$ ℃	P_{in} (kPa)	P_{out} (kPa)	ϵ	ΔP (kPa)	f
37.3	38.8	44	42	240	220	58.6%	20	6.85×10^{-12}

First of all, testing of water heat transfer efficiency without nanoparticles is considered as shown in table (4.1). Temperatures of both air and water are measured at radiator's inlet and outlet, as well as pressure drop, using the temperature and pressure gauges. Out of these data, effectiveness, which is the heat transfer efficiency is calculated using equation (3.1). Also, the friction factor between the fluid layers is recorded. For the sake of comparing the results with and without nanoparticles, the last three columns are important, which are the effectiveness, the pressure drop and the friction factor. The reason for this specific consideration is that the main goal of our project is to compare the heat transfer rate (effectiveness) and friction factor between water with and without nanoparticles, and also to prove that nanofluids enhance heat transfer with no pressure drop.

Table (4.2): observed data for Aluminum Nano particles

V_{water} L	V_{nano} % of V_{water}	$T_{in,air}$ ℃	$T_{out,air}$ ℃	$T_{in,w}$ ℃	$T_{out,w}$ ℃	P_{in} (kPa)	P_{out} (kPa)	ϵ	ΔP (kPa)	f
13.383	0.1%	36.4	38	42	40	260	240	61.5%	20	6.85×10^{-12}
13.383	0.5%	36.4	37.5	42	40	260	240	42.3%	20	6.85×10^{-12}
13.383	0.9%	36.4	38	40	38	240	220	61.5%	20	6.85×10^{-12}
13.383	1.8%	36.4	38.6	38	36	220	200	84.6%	20	6.85×10^{-12}
13.383	2.7%	36.4	39	38	34	200	180	50%	20	6.85×10^{-12}

The same data after adding to the water Aluminum nanoparticles is recorded as shown in table (4.2). Theoretically speaking, as the volume fraction of nanoparticles increases, the heat transfer rate also increases. However, when we put this theory into practice, things got missed up. As we can see from the table, the effectiveness varies significantly as the volume fraction of Aluminum increases. A number of explanations can be provided to justify this inconsistency. Looking at the effectiveness at 0.1% and 1.8% of Aluminum, we can see that it is 61.5% and 84.6% respectively, which means that the effectiveness within this range of Aluminum volume fraction is increasing, but environment's conditions prevented this from happening. One of the reasons that the test was conducted early morning, around 5 a.m., when the temperature was cool and some cold wind was hitting the radiator which caused a portion of heat to be lost.

Additionally, we can see that the effectiveness has dramatically dropped when Aluminum volume fraction was 2.7%. One of the mistakes we made in conducting this experiment is that we test different volume fraction of nanofluid directly one after another, which caused variations in the temperature of nanoparticles between the one added and the one already flowing in water. This effect was seen clearly when volume fraction was 2.7%

Table (4.3): observed data for Cupper Nano particles

V_{water} L	V_{nano} % of V_{water}	$T_{in,air}$ ℃	$T_{out,air}$ ℃	$T_{in,w}$ ℃	$T_{out,w}$ ℃	P_{in} (kPa)	P_{out} (kPa)	ϵ	ΔP (kPa)	f
13.383	0.1%	33.3	34.6	40	38	260	240	50%	20	6.85×10^{-12}
13.383	0.5%	33.3	34.8	40	38	260	240	57.7%	20	6.85×10^{-12}
13.383	0.75%	33.3	34.5	40	38	260	240	46.1%	20	6.85×10^{-12}
13.383	1.0%	33.3	35.1	38	36	240	220	69.2%	20	6.85×10^{-12}
13.383	1.5%	33.3	35.5	38	36	240	220	84.6%	20	6.85×10^{-12}

The table shown above indicates the data obtained when Cupper nanoparticles is added to the water. When another nanoparticles was used, the theory of heat transfer with nanofluids is almost apply, noting the increasing effectiveness between 0.1% and 1.5% volume fraction of Cupper. Nevertheless, at 0.75%, the effectiveness surprisingly decreased, not following the ascending pattern of volume fraction and heat transfer rate. The reason for that is the same environment's conditions explained earlier.

Now, let us look at the other two important parameters: pressure drop and friction factor. As stated at the beginning of the report, one of our project objectives is to prove experimentally what already has been proven theoretically that Nano fluids would increase the efficiency of a system with a slight or no pressure drop. As observed from the data generated from water alone and water with nanofluids, the pressure drop in all cases was constant with 20 kpa. Another important notice is that friction factor had remained constant in all stages, which indicates that adding nanoparticles to fluids has no effect on friction between the layers of fluid.

CHAPTER 5

Chapter 5: Project Management

5.1 Project Plan:

Our project plan was implemented and designed to help us reach the project's objective in the planned time span, therefore a step-by-step execution plan was required. There are important perspectives that were contemplated in this arrangement; extend time administration, meeting the project outline and targets, over all high productivity of the project. The following (Table 5.1) demonstrates the usage arrange with respect to time, task and description.

Table (5.1): Dates, tasks and description of all the tasks.

Week	Task	Description
1	Design of the project phase 1	Stating the require parts and material specifications.
1	Market survey	Looking for equipment and parts in respect to price, functionality and quality.
2	Design of the project phase 2	Using the result form our market survey to design the system.
2	Design testing system phase 1	First system design draft using solid works.
3-4	Purchasing the system parts	This step includes gathering the financial plan and buying the required parts.
5	Assemble the system	Building the testing system using expert technicians for electrical wiring.
6	Checking the system functionality	Checking the system for any water leakage our any insulation problems.
7-8	Data gathering phase 1	Collecting data without using Nano-fluids.
9-10	Data gathering phase 2	Collecting data using Nano-fluids.
11	Data analysis	Comparing the results and the effect of Nano-fluids to

		the heat transfer rate.
12	Finishing the report	Writing the analysis and result parts and finalizing the report.

5.2 contributions of team members:

Table 5.2 demonstrates the fundamental work and project targets and tasks and how much each member in the group contributes separately to accomplish the primary goals of the teamwork.

Table (5.2): shows the rate of work that's done by each group member in regard to the assigned task.

Task	Nasser	Ammar	Abdulrahman	Meshari	Abdullah
Complete literature review	**100%**	**100%**	**100%**	**100%**	**100%**
Design	**100%**	**100%**	**100%**	**100%**	**100%**
Part purchase	**100%**	**90%**	**100%**	**80%**	**80%**
Assembling the system	**100%**	**100%**	**80%**	**90%**	**80%**
Oral presentation	**100%**	**100%**	**100%**	**100%**	**100%**
Testing	**100%**	**100%**	**100%**	**100%**	**100%**
Progress reports	**90%**	**90%**	**90%**	**90%**	**100%**

Thesis writing, Poster, PowerPoint, finalizing the report	**100%**	**100%**	**100%**	**100%**	**100%**

5.3 Project Execution Monitoring

5.3.1 Meetings with Advisors

To be in the right track, our plan was to meet the advisor Dr. Esam Jassim every two weeks to follow up on our progress in the project and show him the results and some issues in order to discuss and find solutions and directions. So the best decision was to meet and follow up with him once every two weeks and based if we needed the required help or faced some difficulties to save time. Therefore, we met him whenever we need to and sometimes we did meet him more than one time a week either within our group or if he could attend and honestly our doctor was the best advisor for guidance and correct directions.

5.3.2. Team meetings

At the first week, we distributed the tasks among our group and our plan was to have a gathering meeting every weekend to follow up on our project updates and due to the project split into two phases, it is a must to follow up almost every day to achieve and complete it within the deadline and the required quality. Actually, there were some short-period meetings that didn't last for more than an hour and the other hand, several meetings could take up to the entire day to finish. At the end of all group meetings, it came to the most important gathering before meeting our advisor either we had issues with the project or this was what we came up with to save our and the doctors' times as possible as we can. And seriously the group was cooperative and positive to successfully implement our project.

5.3.3 Other activities.

Since our project had two parts, the first part was to do the adequate preparation and organization where the other part was to do some experimental tests to prove the excellence of the theory. And because we run of time, we shall to work on it and exert more efforts to finish it on time and therefore we had determined times for every part in details to achieve our target for the final experiment. As all you know, the final phase was our priority although we had facing a lot of obstacles.

5.4 Challenges and Decision Making

Literally, we couldn't have any issues with the group gathering except the time conflicts among our team member and we had resolved it out either by meeting on weekends or in whenever we had some free time. Other than that, all team members were collaborative and supportive wherever we had any issues related to the project.

We had faced some difficulties finding some of the required parts and when these parts found, they were not be within the good quality. Also our biggest problem was the continual changes of these parts to execute and finish our project in a good picture. These were some of the issues we had met with:

5.4.1. Pipes

Due to the plenty of pipe's inputs and outputs and the redundant cutting to connect it either with the radiator, the pressure gate or to the thermometer to avoid any failure such as leaking during the startup of our project, because of that, we had a lot of technical issues with the pipe since the modifications were almost undergoing until we had the correct size which was 31.80 mm and we have got the best results without any leaking for the remaining of our project.

5.4.2. Radiator

We had got some difficulties finding the qualitative and best price radiator and frankly our main issue was the high price of the radiator so we had tackled this issue and found a good quality radiator in one of the best cars.

5.4.3. Fan

We had not find a lot of issues in finding fans but we had changed it three times due to the big size of the radiator and to approach the best required cooling. Also, we had faced another issue with the big-size fan and therefore we posted a caution sticker which no close approach from all sides to prevent any incidents and especially between the fan and radiator due to the high speed and large blades.

5.4.4. Ultrasound

Our biggest challenge is the programming stage but we asked for help from students majoring in Electrical Engineering in the university also we tackled another issue related to distributing the ultrasound to prevent the Nano particles from getting to each other. So the best solution was to arrange the ultrasound equally under the container.

5.4.5. Temperature and pressure gauges

No serious issue observed finding the temperature and pressure gauges other than the high price in the market and it was more costly once we had used two pressure gauges and two temperature of each parameter to measure inside and outside.

5.4.6. Household water heater

One of the issues we had a solution for is looking for the appropriate container to fit the pipe and we found the Household is the best due the easy fitting but another issue had been raised in putting the heater inside it and what was the proper temperature for it. So our Dr.Esam Jassim helped us and told us to start up the system and left it till the water being constant and then put in the heater below the water level and adjusts the water temperature to 30 Celsius degrees. Technically, it wasn't considered a big problem since we had changed the container several times to suite the project.

5.4.7. Nano particles

Due to unavailability of the Nano particles in the local market and one of the biggest challenges we had faced was finding the most trusted and secured online website to procure and the needed quantity for the project but it had been resolved by buying these stuff from one of the American websites and it is one of the biggest companies in the Nano technology. However, it took three weeks to receive the package and it was really another issue delaying our progress.

5.4.8. Pump

One of the biggest and most important issues is getting the adequate pump although it is available in our local markets but the sizes and the pumping speed was different and since our project had experienced a lot of changes so the pump had the opportunity to change more than once. And because of that, we had spent time in trying different types of the pump until we had found the one met our needs.

Also, one of the secondary issues we had confronted with was finding the appropriate table for our giant project and therefore we had taken the required measures and made a special table for us and that was another financial issue that cost us more than SAR 600.

5.5 Bill of Materials

This table (5.5) represents the bill of material of the system

Table (5.5): Bill of material

Item	Quantity	Cost S.R
Nano particles	2	1200
Table	2	400
Fan	1	650
Radiator (Heat exchanger)	1	180
Water container	1	90
Water pump	1	350
House	2	360
Pressure gage	2	60
Thermometer	2	240
Electricity wiring		100
Technician work		300
Manufacturing tubes in the water container		350
Heater	1	45
Tubes, elbows, connectors and glow		300
Masks and gloves	2	60
Frames	2	200
Shipping and transportation		150
Rollup and brochure	1 , 25	360
Leather bounded book	3	900
Total	48	6295

CHAPTER 6

Chapter 6: Project Analysis

6.1 Life-long Learning

There were many things that were implemented by us during the time we did this project. The nature of the project required the use of many new devices and components, but we did have to improvise with other things. The short time we had to do the project also constrained our ability due to tight deadlines. This project involved highly detailed measurements due to the nature of the material we are working with, and the environment we are working in. We had to use many time management methods, specialized components, and also complex CAD designs.

The first major hurdle that we needed to face was the time we had. Within the span of less than four months we had to design, manufacture, assemble, and test our theories. A project plan was implemented and designed to help us reach the project's objective in the planned time span, therefore a step-by-step execution plan was required. Hence a gnat chart was created, and deadlines were set. There were deadlines from the instructor, and others we set for ourselves. The gnat chart aided us in formulating and visualizing our tasks for the months that were to come. We had to learn how to detail it in a way that fits with our needs and time constraints.

The second hurdle was finance. Being students we only have limited financial capabilities, and we have to work within our means to achieve our project objectives. We had to learn to manage our finances properly, and therefore we had to do some of the work ourselves, or come up with novel solutions for the issues. In instance like heating the water we made the decision to use a water container we had and only the heating mechanism of a water heater. That saved us a lot of money.

The third hurdle was specialized components. We have none of the equipment's that are available in major universities or companies. We had to come up with the least amount of sensors that would produce valid and accurate results. We had to start with choosing out Nano particles. The sheer number of available ones made our task very difficult. We opted to using the ones that were mentioned in previous studies. We had to learn to handle them in a way as to not harm ourselves or our surroundings. After that we had to create the ultrasound device from off the shelf components, which was also a cost and time cutting measure. As for the testing we had to come up with a method that would result in accurate readings without requiring extra sensors. For example we would test the surrounding air temperature once before each specific test, and use the same sensor for testing the temperature after the air passes the radiator.

The fourth hurdle is designing a system that would work. We had to design our system from scratch without having any previous work to build off. We started by modeling our idea of the prototype using SolidWorks. We got the program from the university after going through the Computer Aided Design course. We also used the computer labs provided by the university for this purpose. We used tutorials from YouTube to be able to design the prototype faster and easier. For example the fan we made we used the twist to get the curing shape on the fan blades. We were also able to use a pump and valves that were predesigned and part of the software. This greatly aided our visualization, and designing time.

6.2 Impact of Engineering Solutions

In the most basic sense of our work the idea is efficiency. That is our key, and that is what we need to achieve. If we can show that current equipment could be configured to do much more than designed that would save a lot of money. The impact of the project touches many areas of our lives from the power coming to our homes to the water we drink even the industrial machines used to transport everything we see. We want to increase the efficiency of everything that heat transfer plays a role in, and we choose to start with radiators, because it is what we could afford with the time we had. Heat transfer plays a role in the transportation, power generation, and even water production.

Increasing the efficiency of transport would decrease fuel consumption. If the efficiency of a ship that transports goods is increased that means it requires less fuel to run, and that makes it cheaper, and that results in more affordable goods for all. If we make the trucks that move ore from mines more efficient that would mean they can work more, and lower the cost on companies making them able to spend more on other things like increasing wages. If we make the cars we currently have run more efficiently that means we lower the fuel consumption, and by that we reduce the carbon foot print on the planet.

Increasing the efficiency of power production would mean lowering their impact on the environment. Most power plants rely on heat transfer, and use water to do that, which we have shown is a very poor conductor of heat. Suspending Nano particles in the water would only require the introduction of ultrasound devices to suspend the particles, and prevent precipitation. That would greatly cut the cost of power, because they can provide the same amount with less fuel, and by burning less fuel we would reduce the carbon foot print on the planet.

6.3 Contemporary Issues Addressed

Our world doesn’t have a finite amount of resources therefore we need to do the most with the resources we are running out of, and we also have to take care of the planet that we are slowly killing. With small changes to even the existing machines and infrastructure we can achieve this. With the rising fuel costs we can have our cars consume less fuel by making them consume it more efficiently. We can also have power plants that are up and running get the most energy out of the fuel they consume, which will save Saudi a lot of barrels that could be sold on the open market. All of these have a compounded benefit because the save the environment.

CHAPTER 7

Chapter 7: Conclusion and future recommendations

7.1: Conclusion

To put our work in a few words, the project was intended to design an experiment to study the enhancement of heat transfer rate in car radiator systems using nanoparticles. We were required to complete the experiment within 4 months and provide a detailed report illustrating our work into it. The main aim of this project is to prove experimentally what already has been proved theoretically that Nanofluids increase the heat transfer rate with no pressure drop. Despite facing some inconsistencies of results due to environment conditions, the goal of the project has been achieved. Another important outcome of this project is that adding nanoparticles to fluids does not affect friction between the layers of fluids

7.2: Future recommendations

In order to further study the behavior of heat transfer in Nanofluids, other types of nanoparticles are advice to be used. Also, to get the best and most accurate results, environment's conditions has to be monitored in a way that they do not affect the experiment negatively, giving misleading data. Furthermore, using a metallic water tank would decrease the use of ultrasound waves. Finally, we recommend experimenting Nanofluids in power plants applications.

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Appendix A: Bill of Materials

Item	Quantity	Cost S.R
Nano particles	2	1200
Table	2	400
Fan	1	650
Radiator (Heat exchanger)	1	180
Water container	1	90
Water pump	1	350
House	2	360
Pressure gage	2	60
Thermometer	2	240
Electricity wiring		100
Technician work		300
Manufacturing tubes in the water container		350
Heater	1	45
Tubes, elbows, connectors and glow		300
Masks and gloves	2	60
Frames	2	200
Shipping and transportation		150
Rollup and brochure	1, 25	360
Leather bounded book	3	900
Total	48	6295

Appendix B: Datasheets

Calculations for Friction:

$$\Delta P = f.\frac{L}{D}\frac{V^2}{2}\rho$$

L=length of radiator tubes =22.8 m

$$\rho = 1000$$

$$\Delta P = 20\ KPa$$

$$\dot{m} = 0.72$$

$$D = \frac{4ab}{2(a+b)} = \frac{4(0.025 \times 0.003)}{2(0.025 + 0.003)} = 0.0054$$

$$V = \frac{4\dot{m}}{\pi D^2} = \frac{4(0.\dot{7}2)}{\pi(0{,}0054)^2} = 31438.1$$

$$\Delta P = f.\frac{L}{D}\frac{V^2}{2}\rho$$

$$f = \frac{\Delta P}{\frac{L V^2}{D\ 2}\rho} = \frac{20}{\frac{22.8}{0.0054}\frac{31438.1^2}{2}1000} = 6.853824253 \times 10^{-12}$$

Calculations for Effectiveness:

$C_c = \dot{m}_c c_p$ =2390

$C_h = \dot{m}_h c_p = 3105.4$

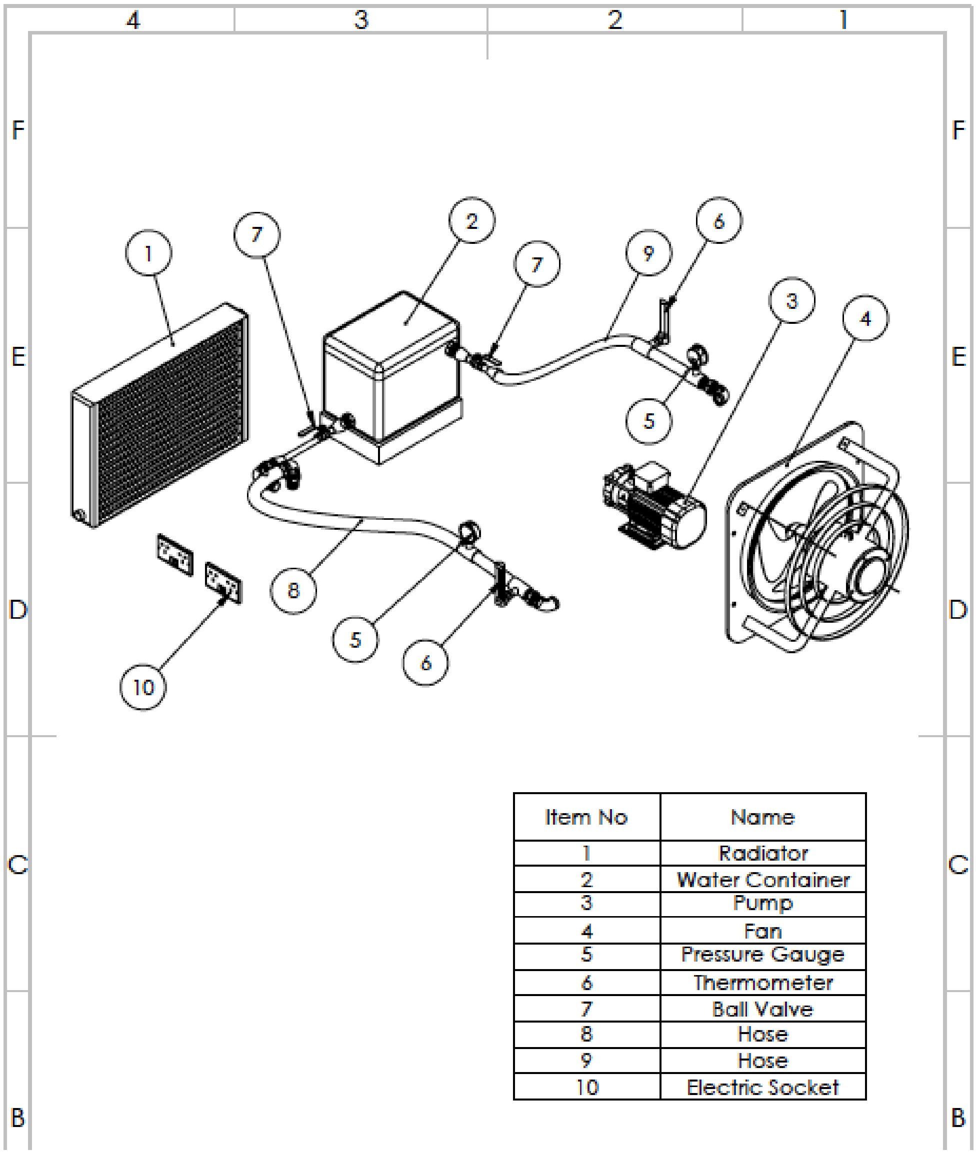
$\dot{Q}_{air} = C_c(T_{in} - T_{out}) = \frac{2390\times1.6}{1000} = 3.824$

$\dot{Q}_{water} = C_h(T_{in} - T_{out}) = \frac{3105.4\times2}{1000} = 6.2108$

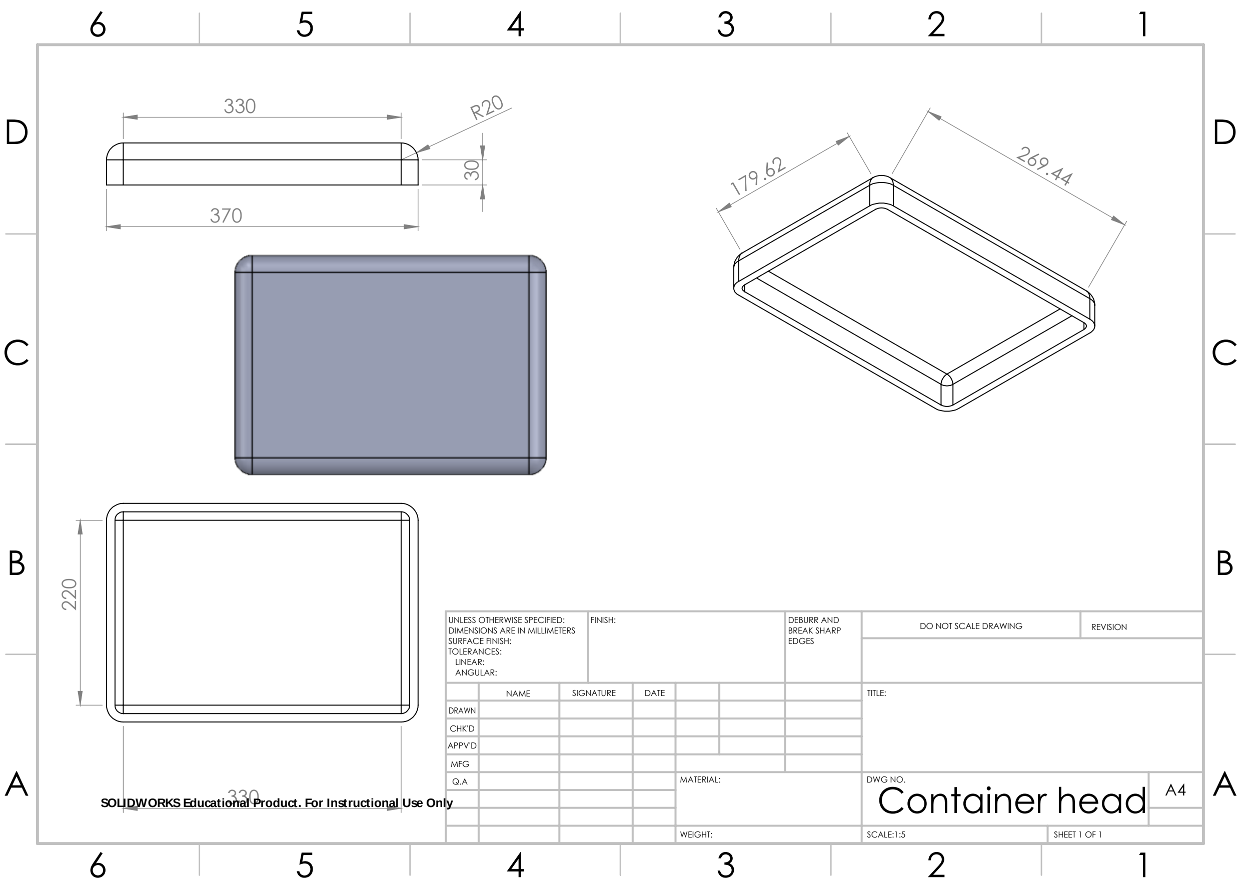
$\in = \frac{Q_{air}}{Q_{water}}$ **Or** $\in = \frac{Q_{water}}{Q_{air}}$ (the greater value is in the denominator) equation (3.1)

$\in = \frac{3.824}{6.2108} = 0.616 = 61.6\%$

Appendix D: Solid Works



Item No	Name
1	Radiator
2	Water Container
3	Pump
4	Fan
5	Pressure Gauge
6	Thermometer
7	Ball Valve
8	Hose
9	Hose
10	Electric Socket



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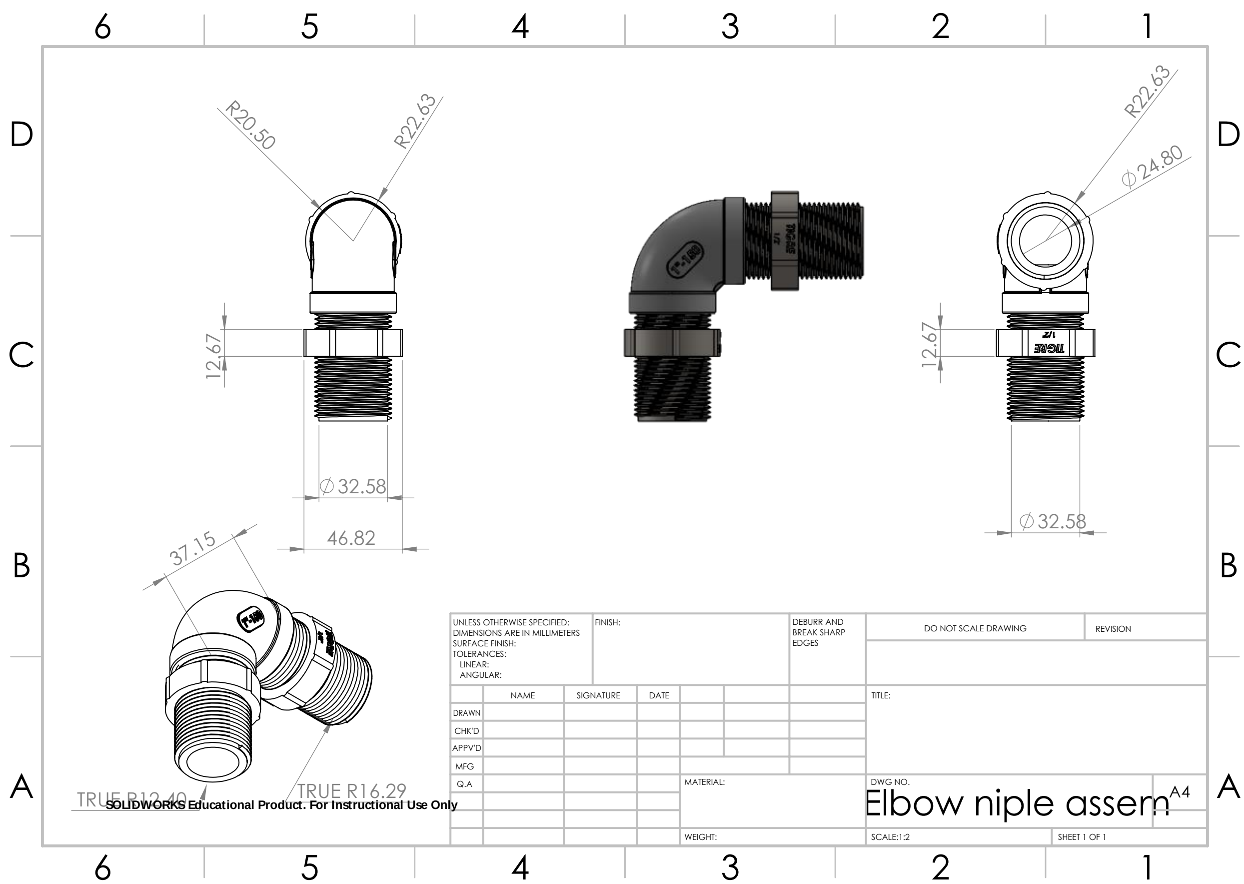
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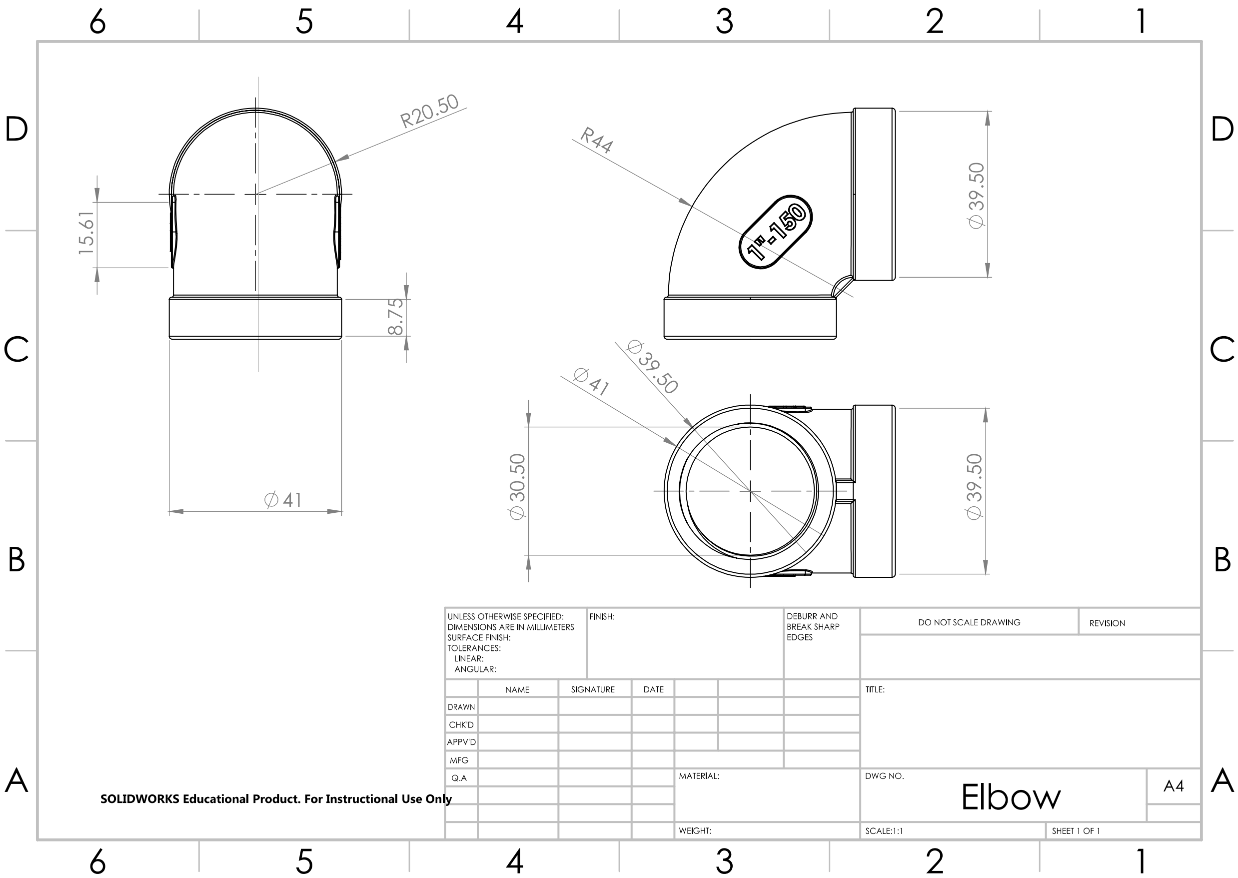
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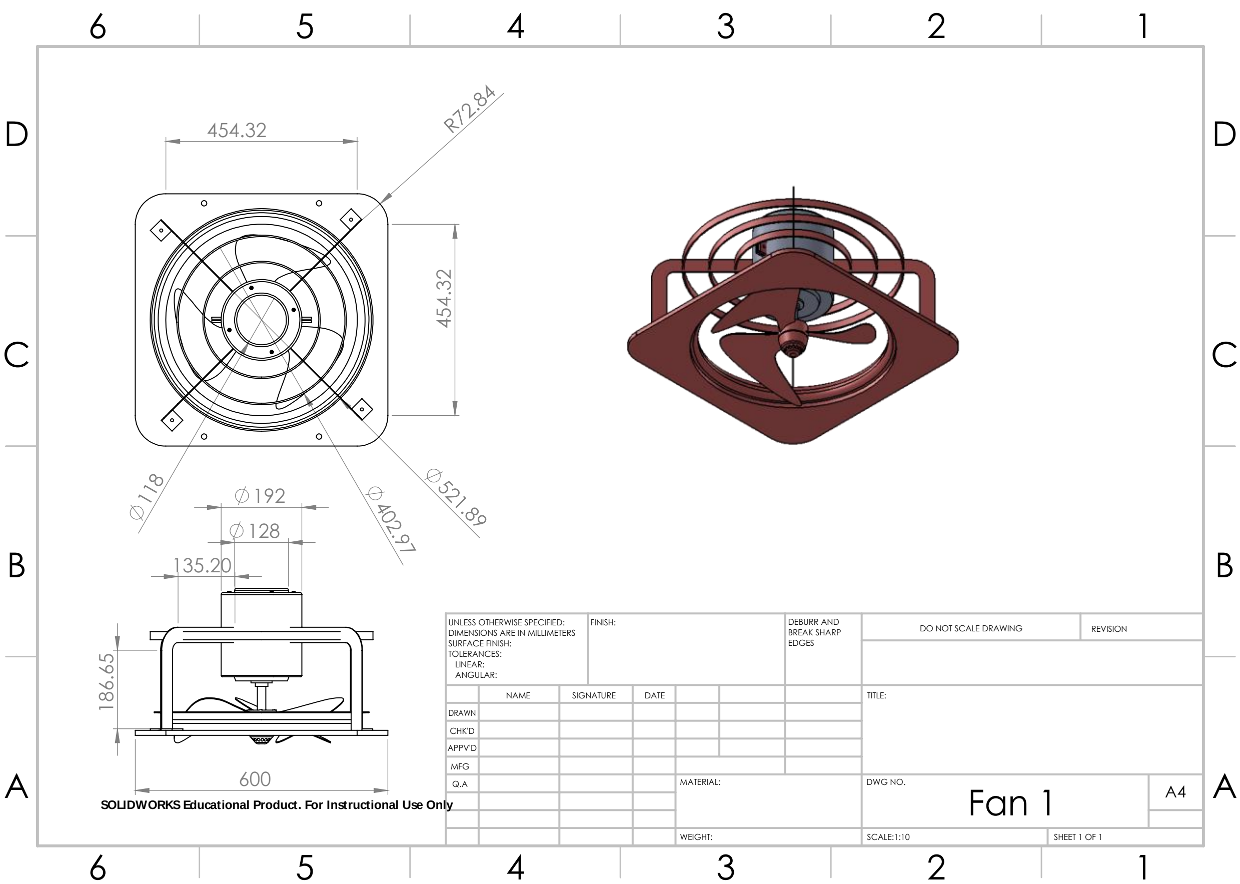

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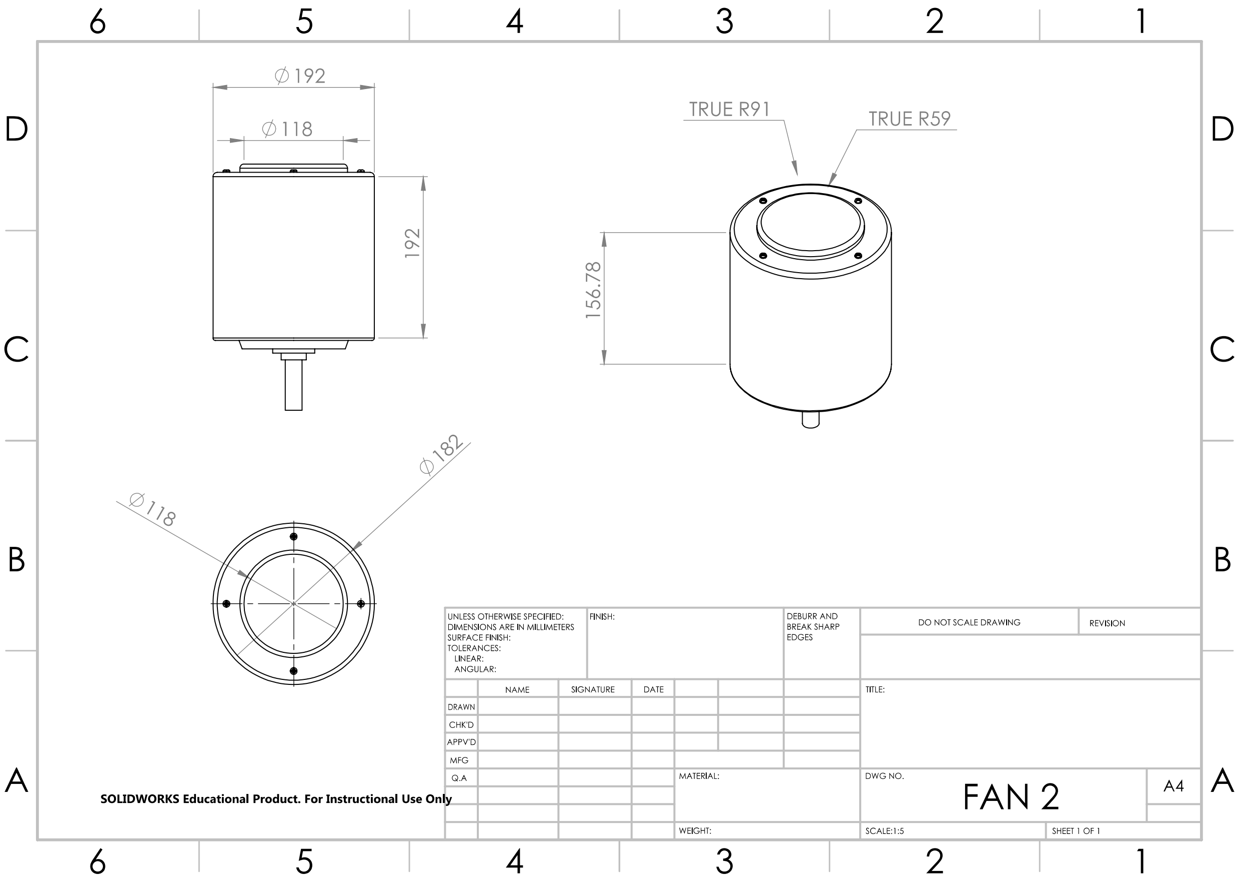

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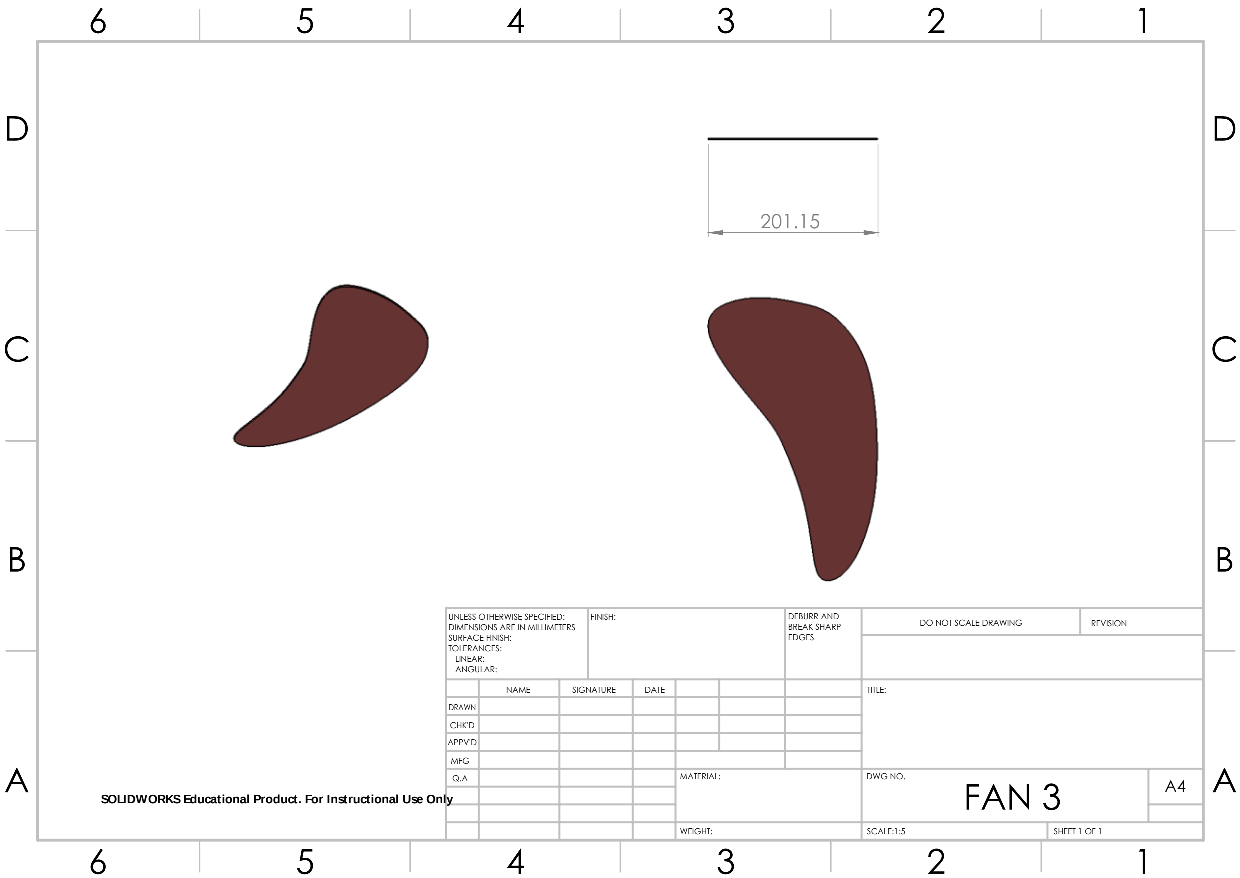
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DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
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A4
WEIGHT:
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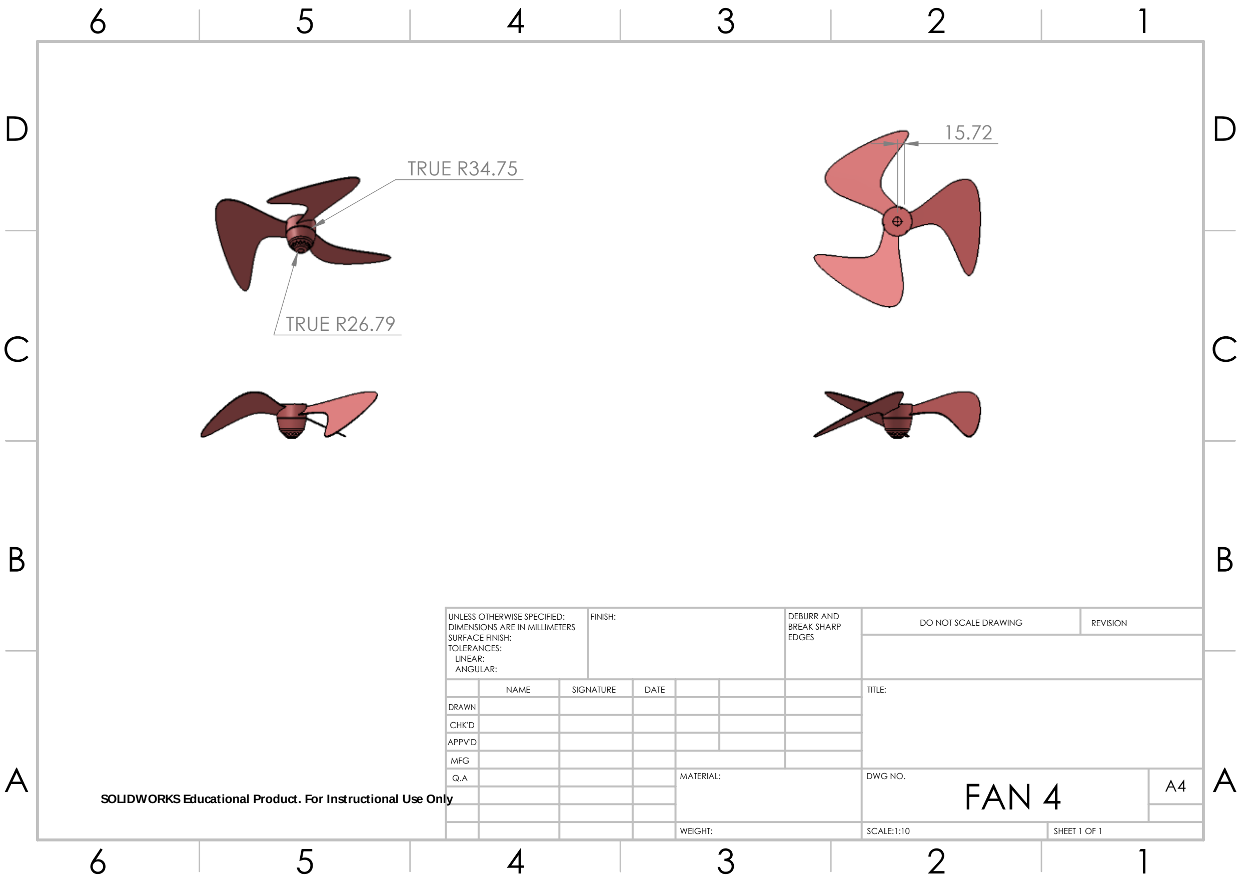
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only


TRUE R34.75
TRUE R26.79
15.72
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ANGULAR:
FINISH:
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CHK'D
APPV'D
MFG
Q.A
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FAN 4
A4
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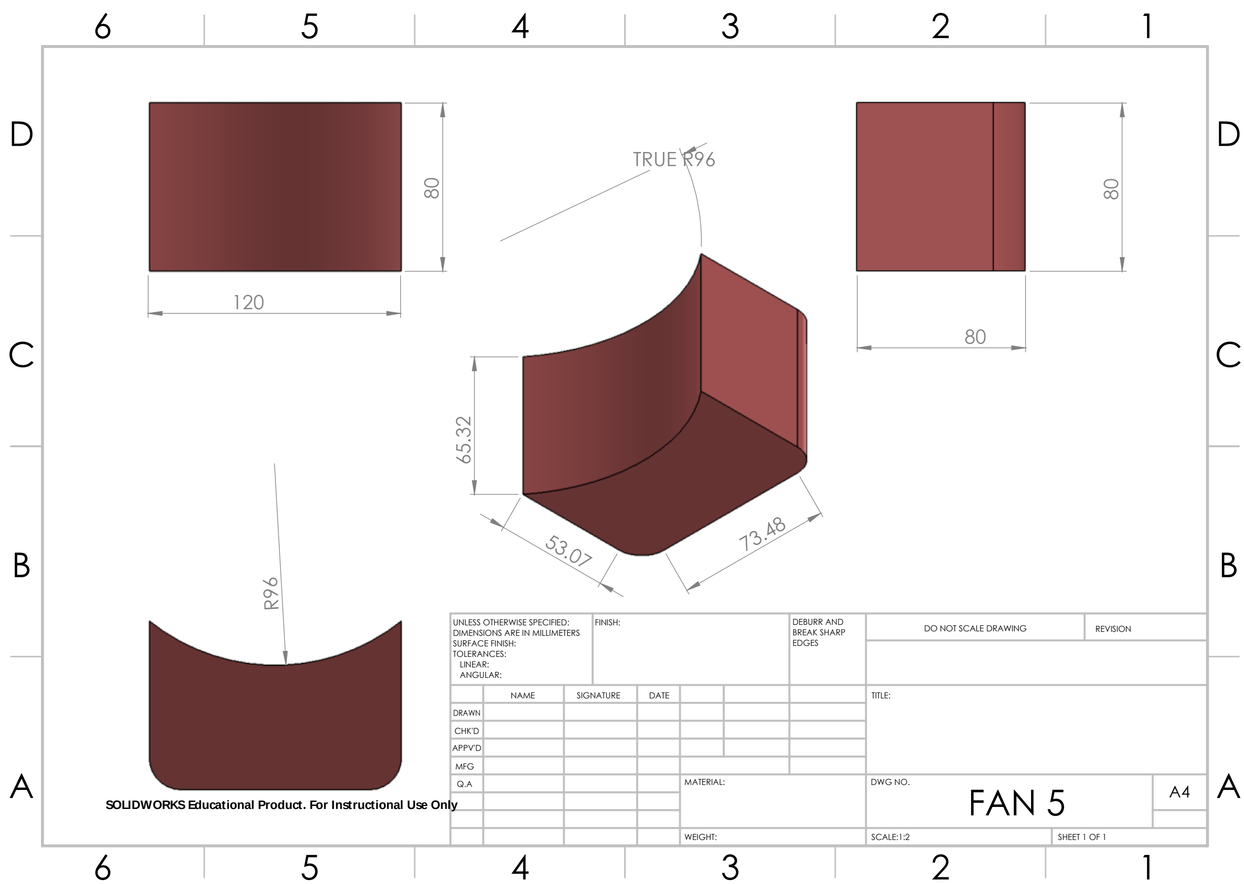
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only



TRUE R96
80
120
80
80
65.32
53.07
73.48
R96
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ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
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SIGNATURE
DATE
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CHK'D
APPV'D
MFG
Q.A
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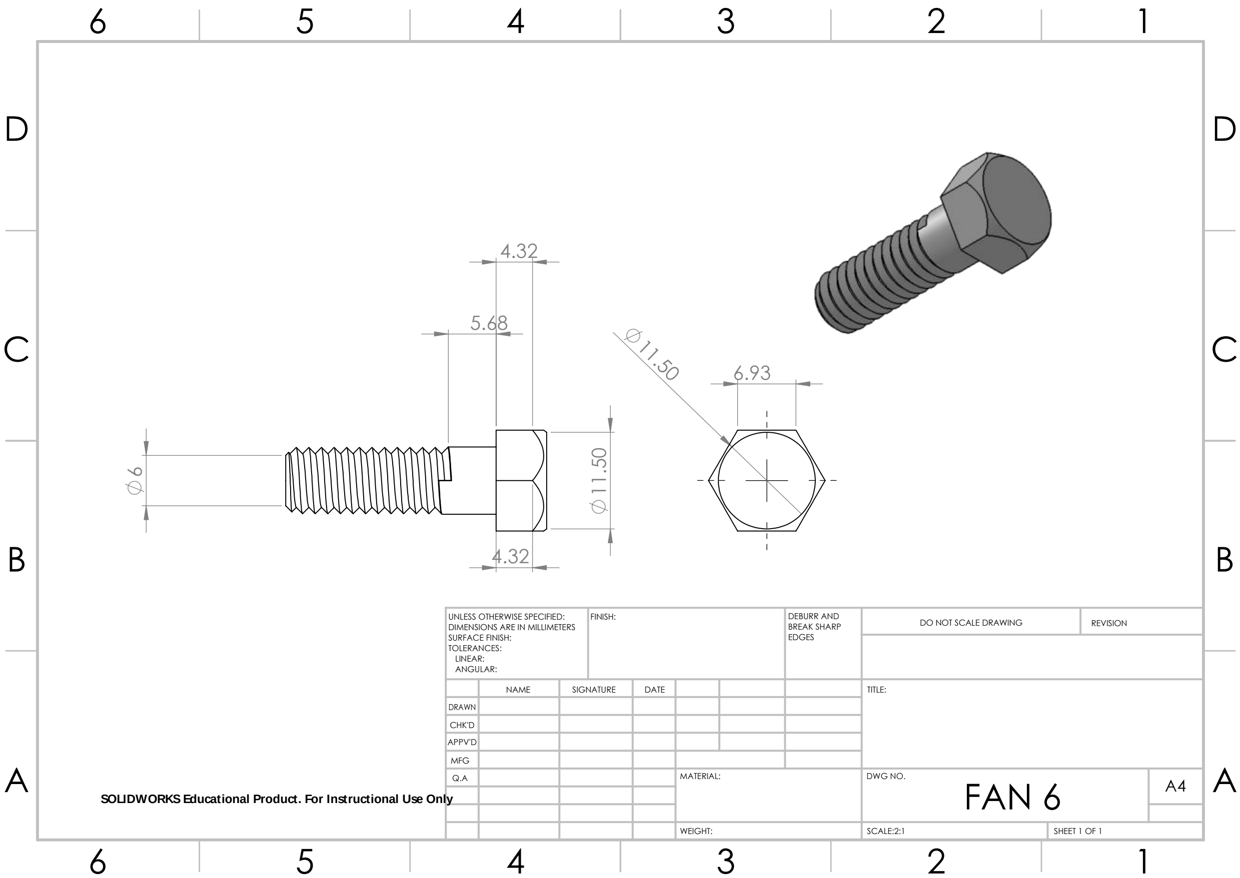
4.32
5.68
⌀11.50
6.93
⌀6
⌀11.50
4.32
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FINISH:
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DO NOT SCALE DRAWING
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APPV'D
MFG
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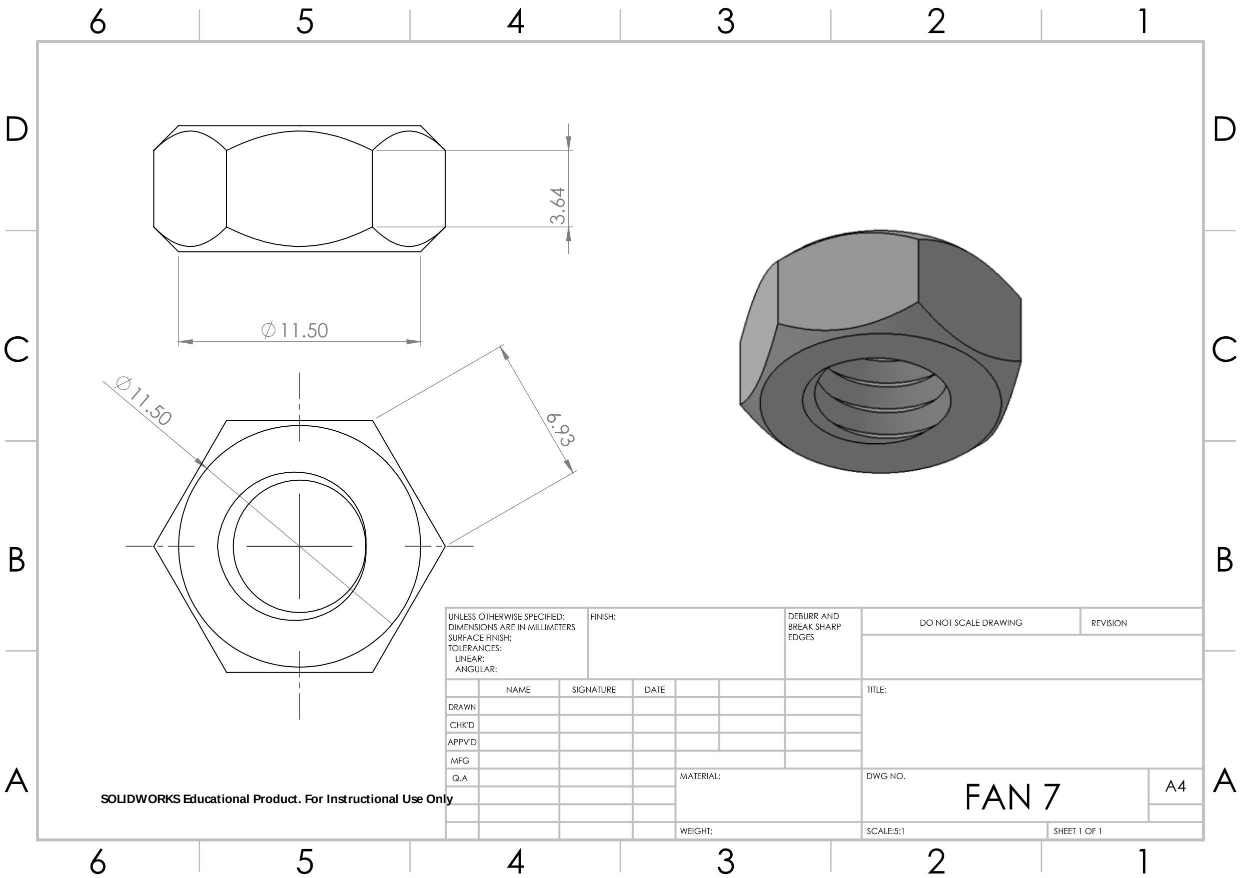
3.64
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Ø11.50
6.93
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LINEAR:
ANGULAR:
FINISH:
DEBURR AND
BREAK SHARP
EDGES
DO NOT SCALE DRAWING
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CHK'D
APPV'D
MFG
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FAN 7
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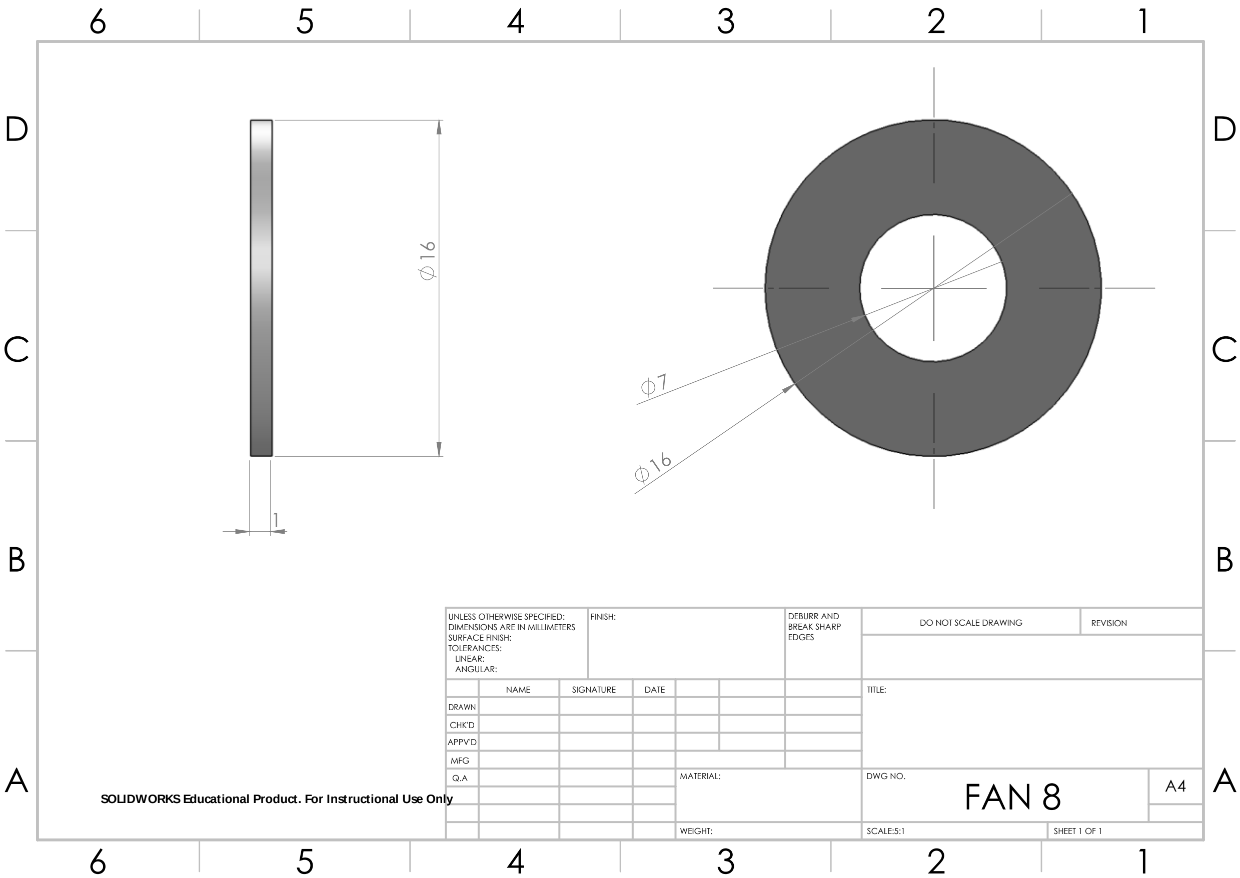
6
5
4
3
2
1
D
C
B
A
⌀16
1
⌀7
⌀16
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TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
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NAME
SIGNATURE
DATE
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CHK'D
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MFG
Q.A
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FAN 8
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WEIGHT:
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SHEET 1 OF 1
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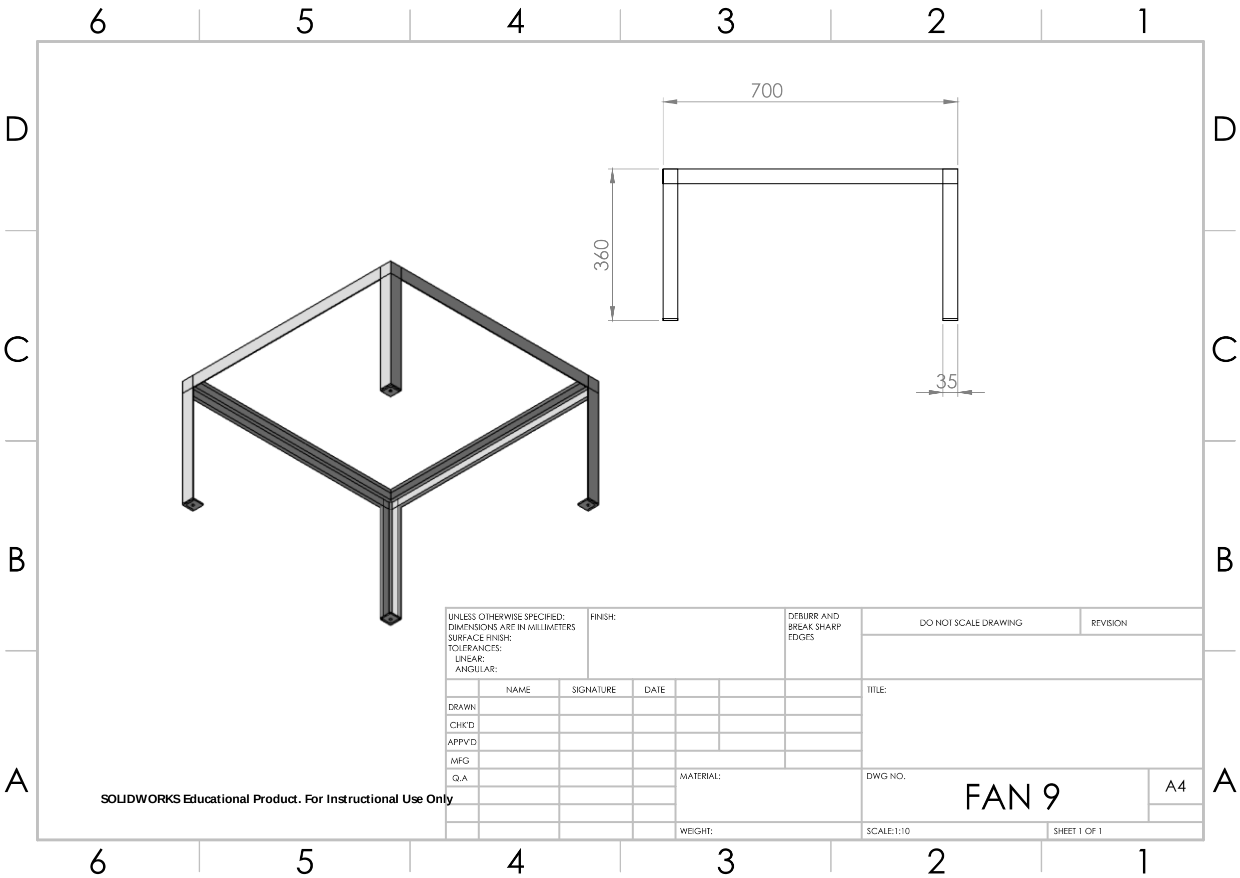
700
360
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FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
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NAME
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DATE
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CHK'D
APPV'D
MFG
Q.A
TITLE:
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FAN 9
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WEIGHT:
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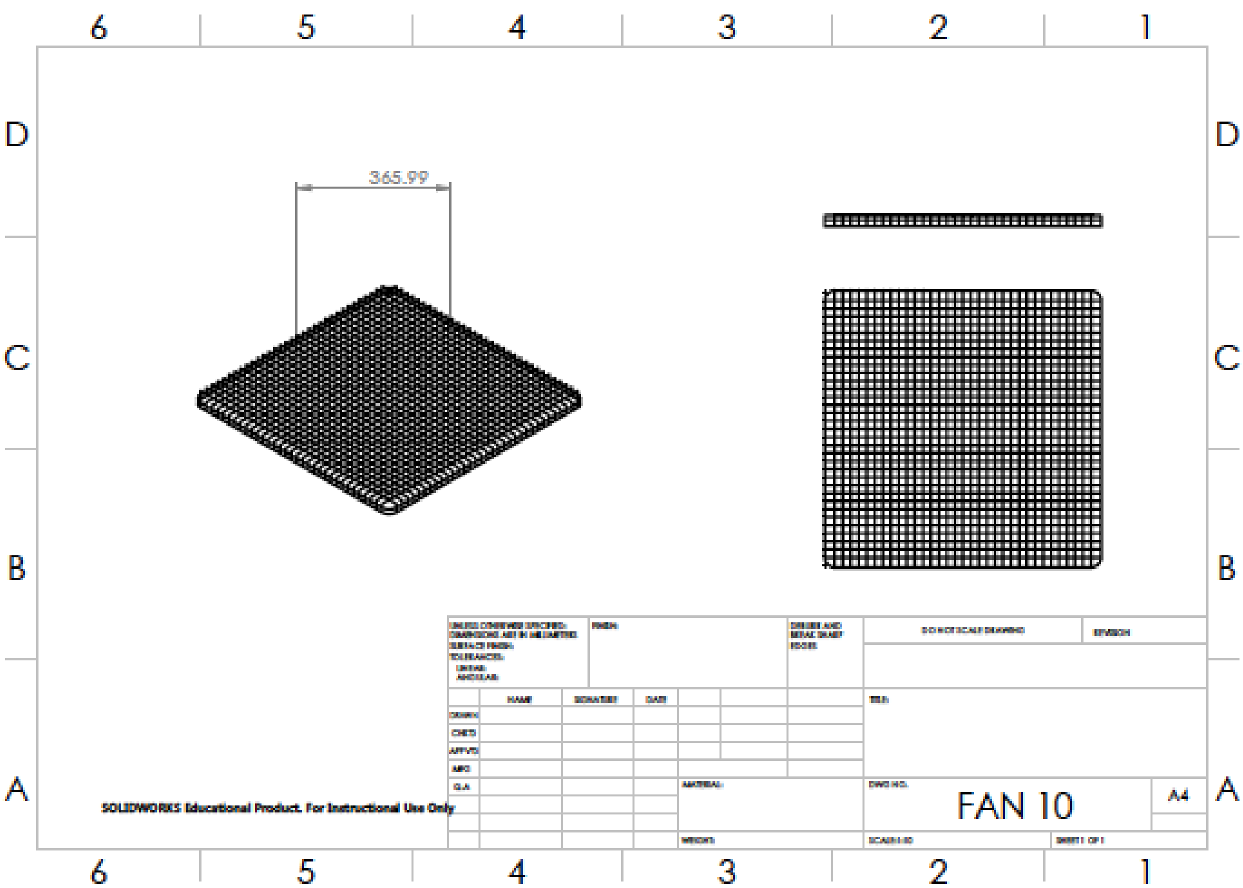
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only



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FAN 10
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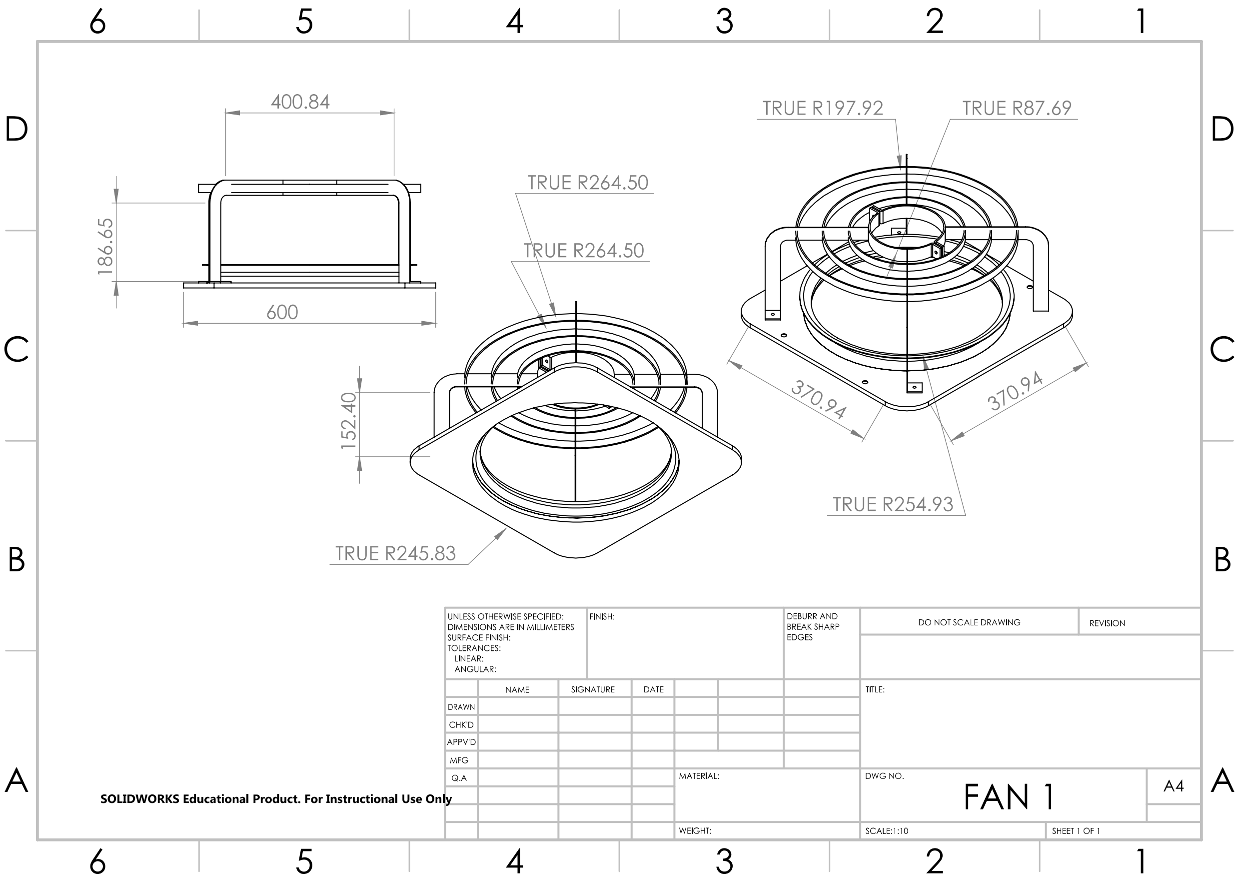

400.84
186.65
600
TRUE R264.50
TRUE R264.50
152.40
TRUE R245.83
TRUE R197.92
TRUE R87.69
370.94
370.94
TRUE R254.93
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
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LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
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DWG NO.
FAN 1
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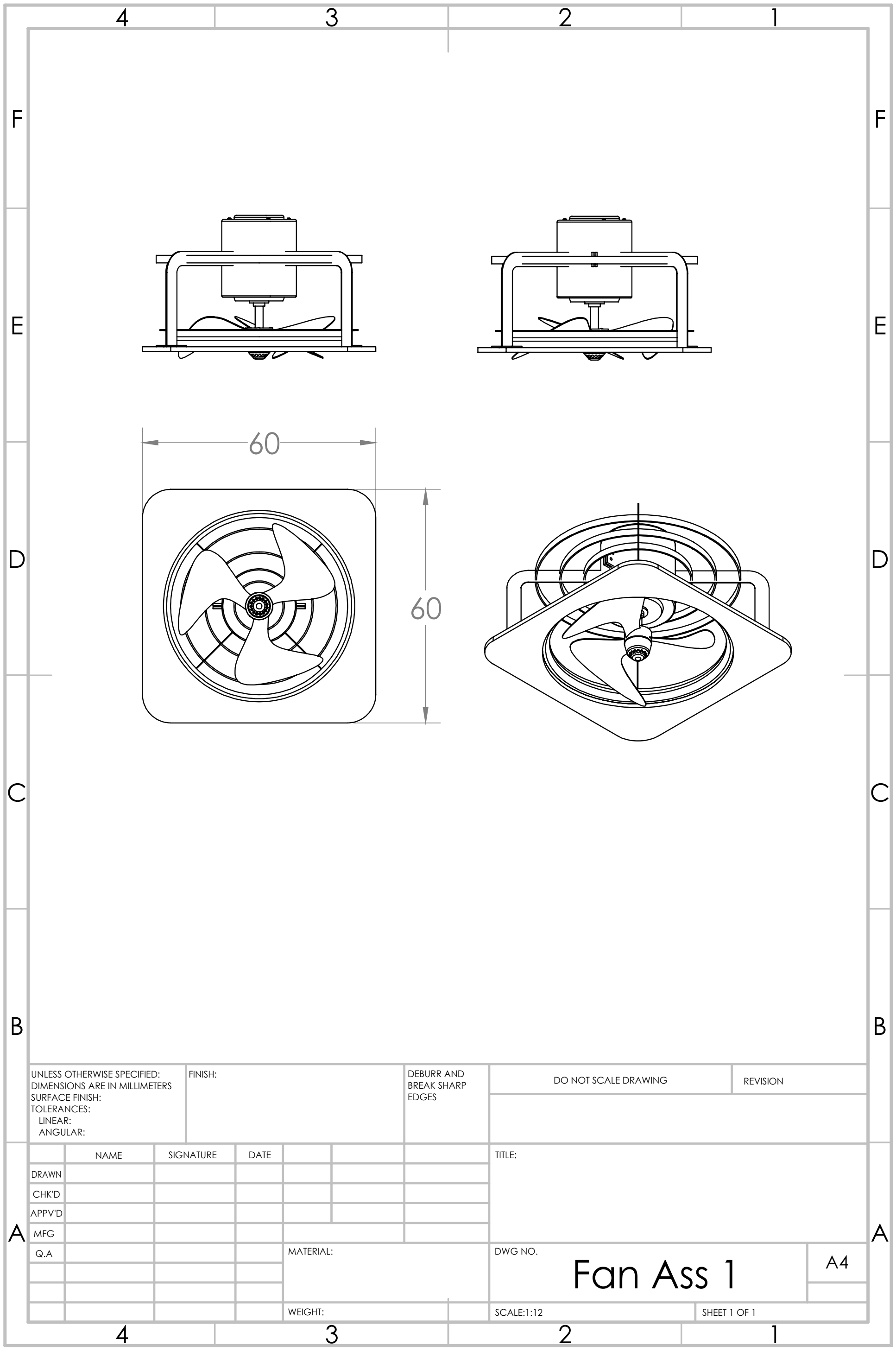
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only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DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
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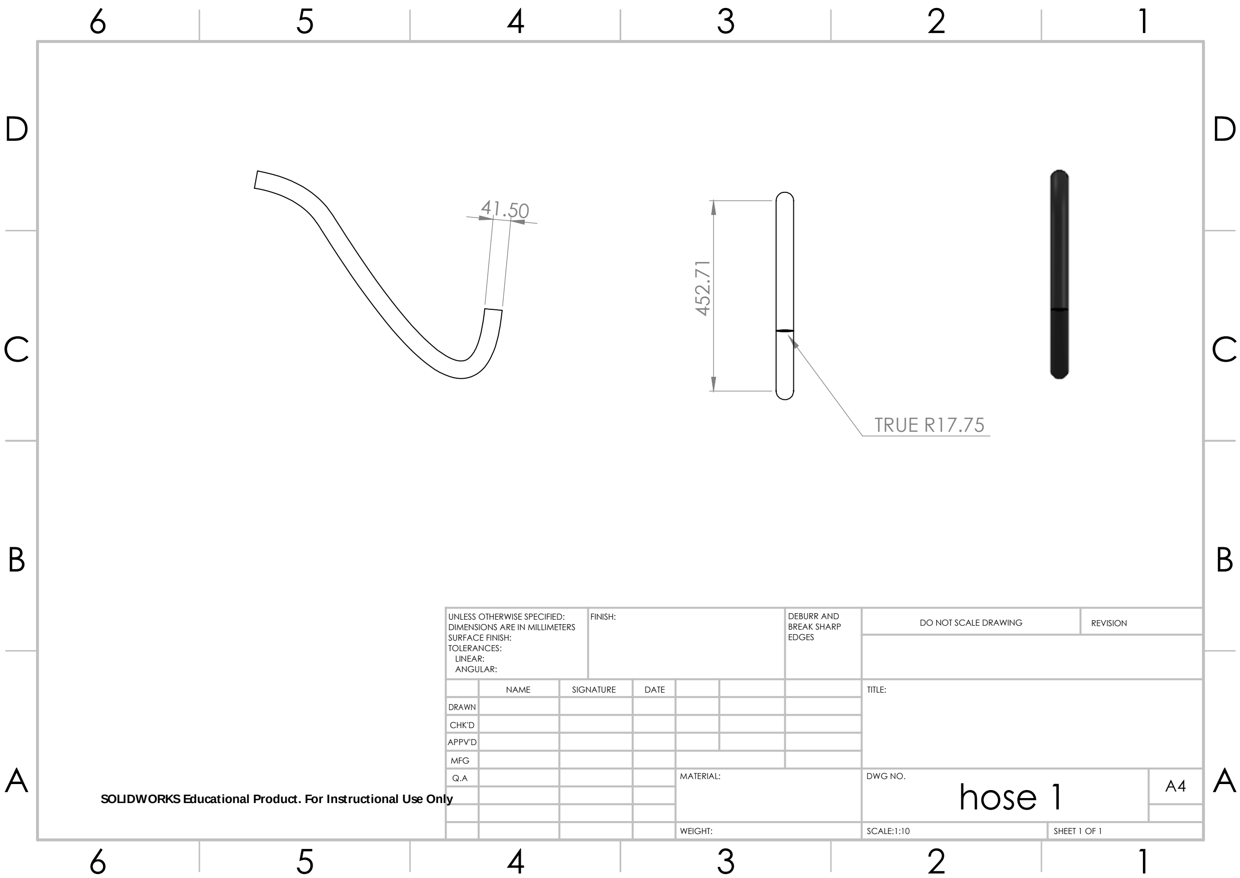
A4
WEIGHT:
SCALE:1:12
SHEET 1 OF 1


41.50
452.71
TRUE R17.75
UNLESS OTHERWISE SPECIFIED:
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TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
DWG NO.
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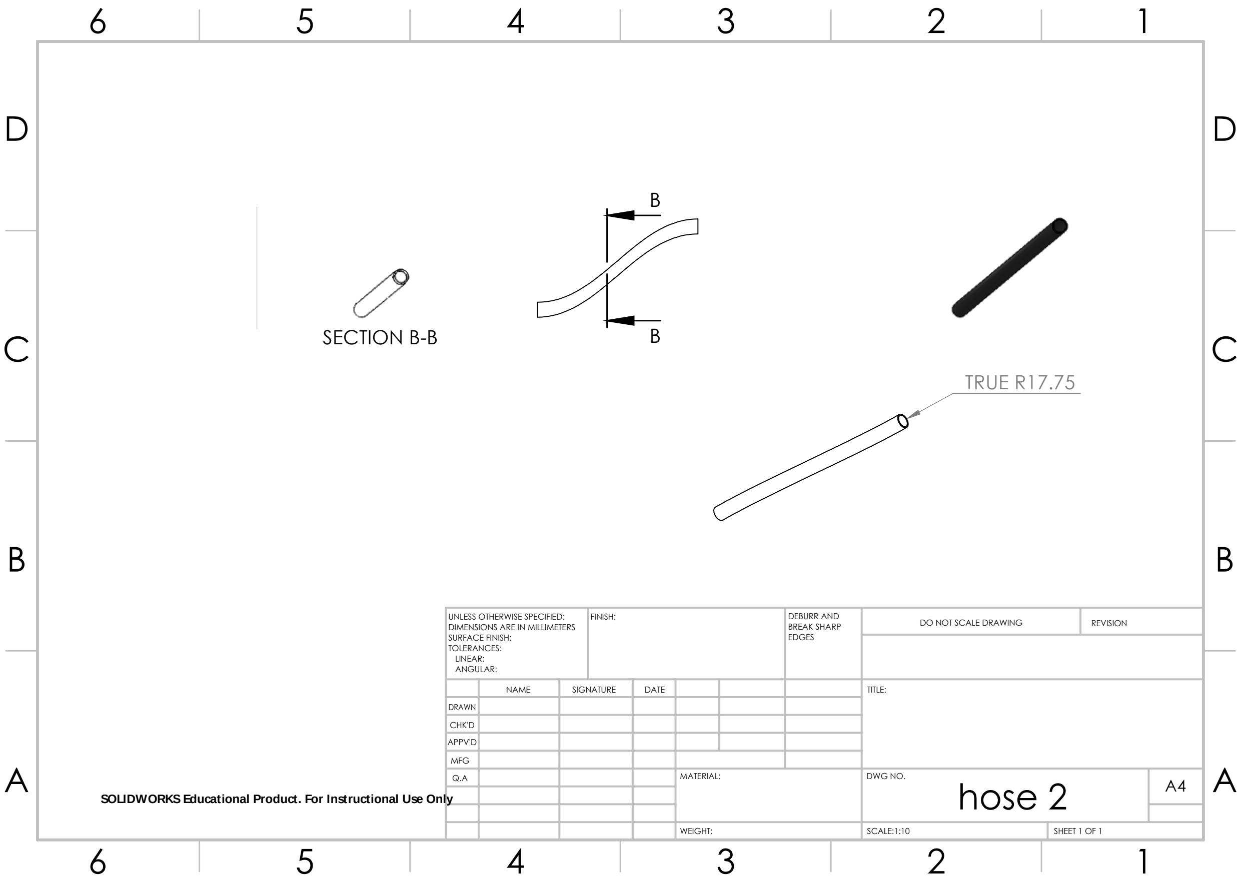
A4
WEIGHT:
SCALE:1:10
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only


B
B
SECTION B-B
TRUE R17.75
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND
BREAK SHARP
EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
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MATERIAL:
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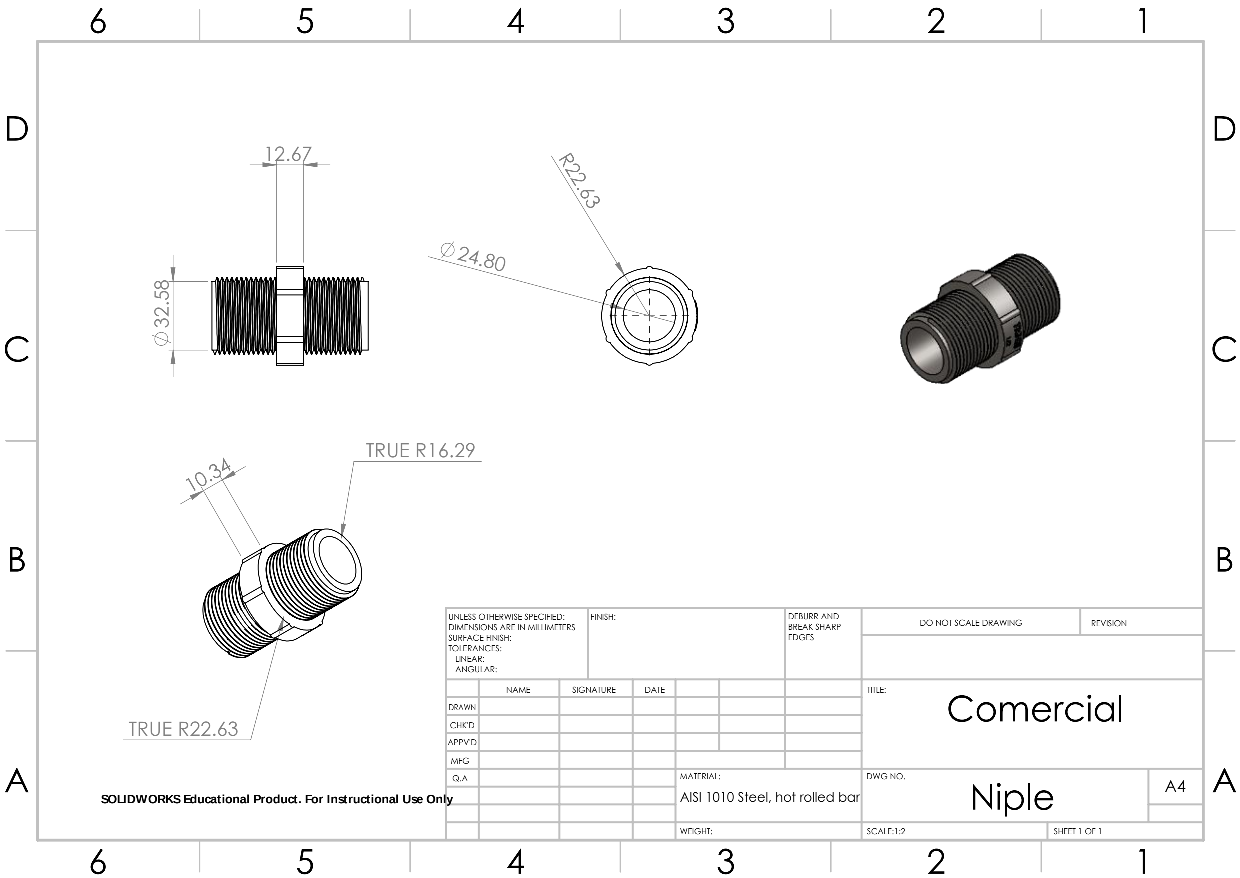
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only


12.67
R22.63
∅24.80
∅32.58
TRUE R16.29
10.34
TRUE R22.63
UNLESS OTHERWISE SPECIFIED:
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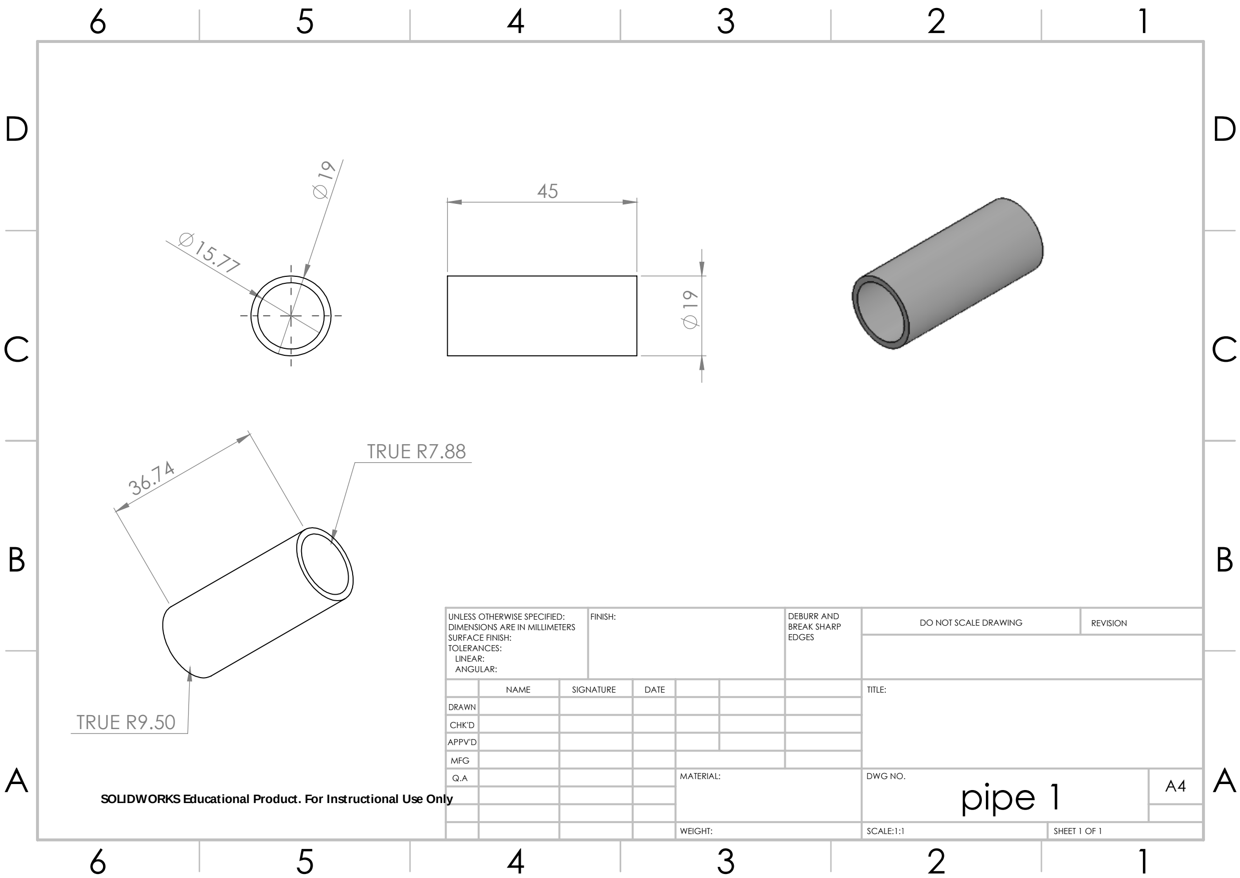
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
Comercial
MATERIAL:
AISI 1010 Steel, hot rolled bar
DWG NO.
Niple
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only



Ø19
Ø15.77
45
Ø19
36.74
TRUE R7.88
TRUE R9.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
DWG NO.
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SHEET 1 OF 1
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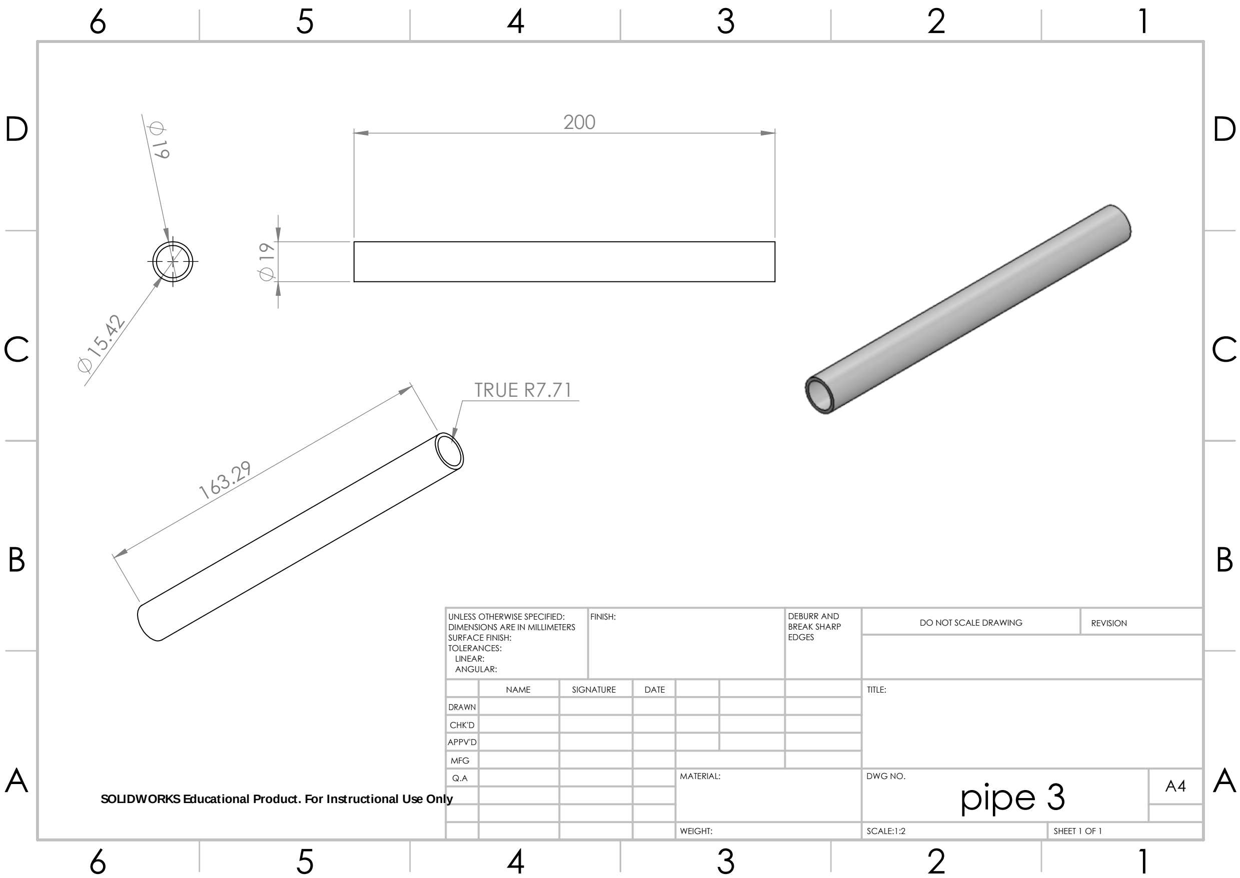
200
Ø19
Ø 19
Ø15.42
TRUE R7.71
163.29
UNLESS OTHERWISE SPECIFIED:
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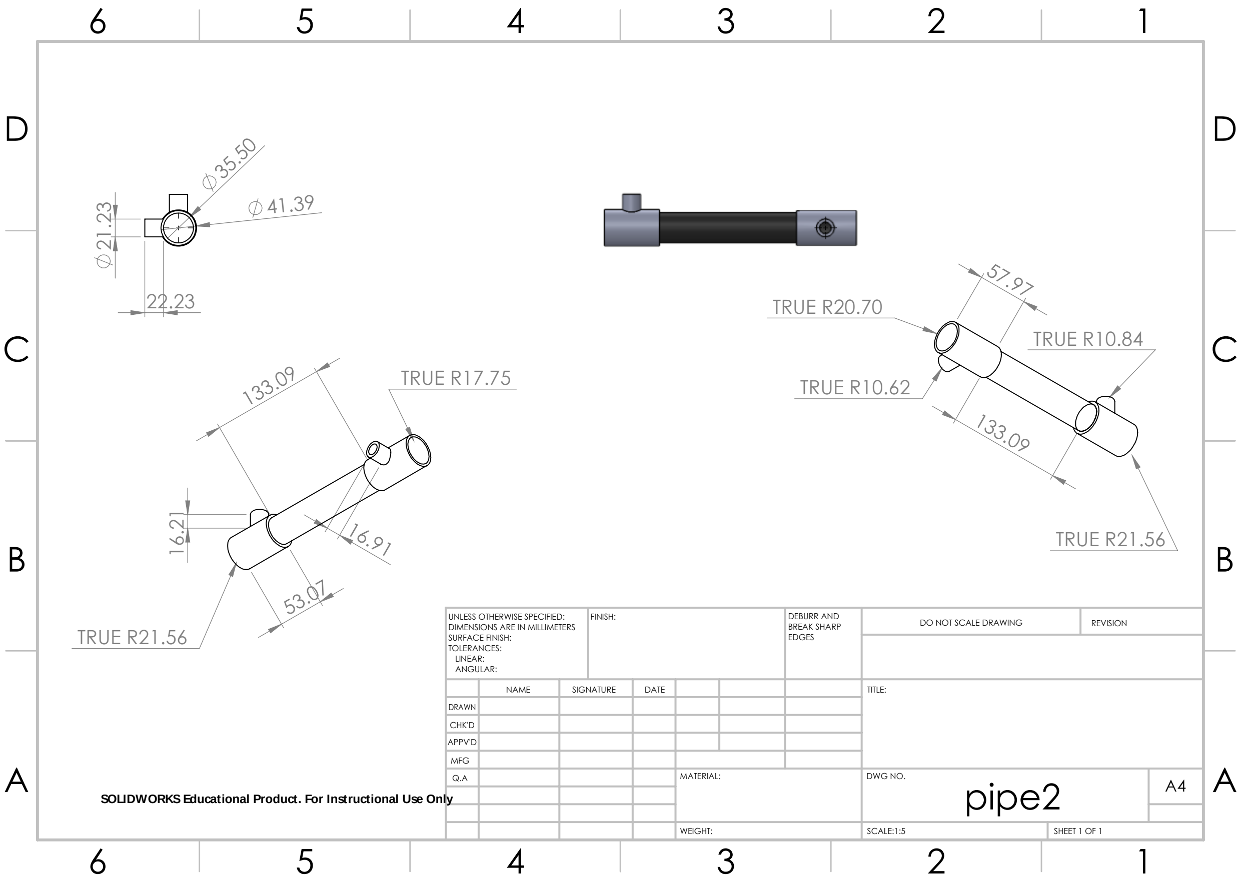
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
pipe 3
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only



∅35.50
∅41.39
∅21.23
22.23
133.09
TRUE R17.75
16.21
16.91
53.07
TRUE R21.56
57.97
TRUE R20.70
TRUE R10.84
TRUE R10.62
133.09
TRUE R21.56
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
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NAME
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TITLE:
DRAWN
CHK'D
APPV'D
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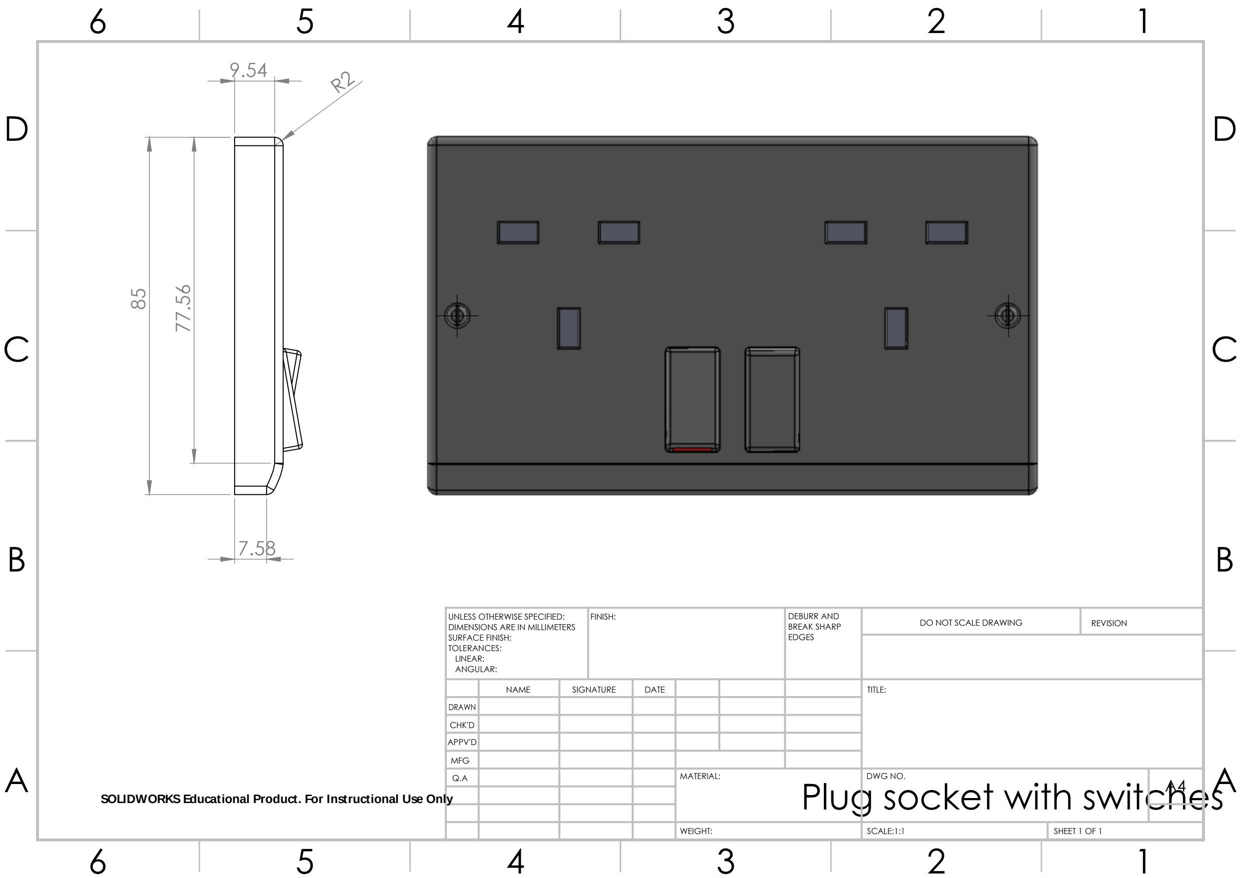
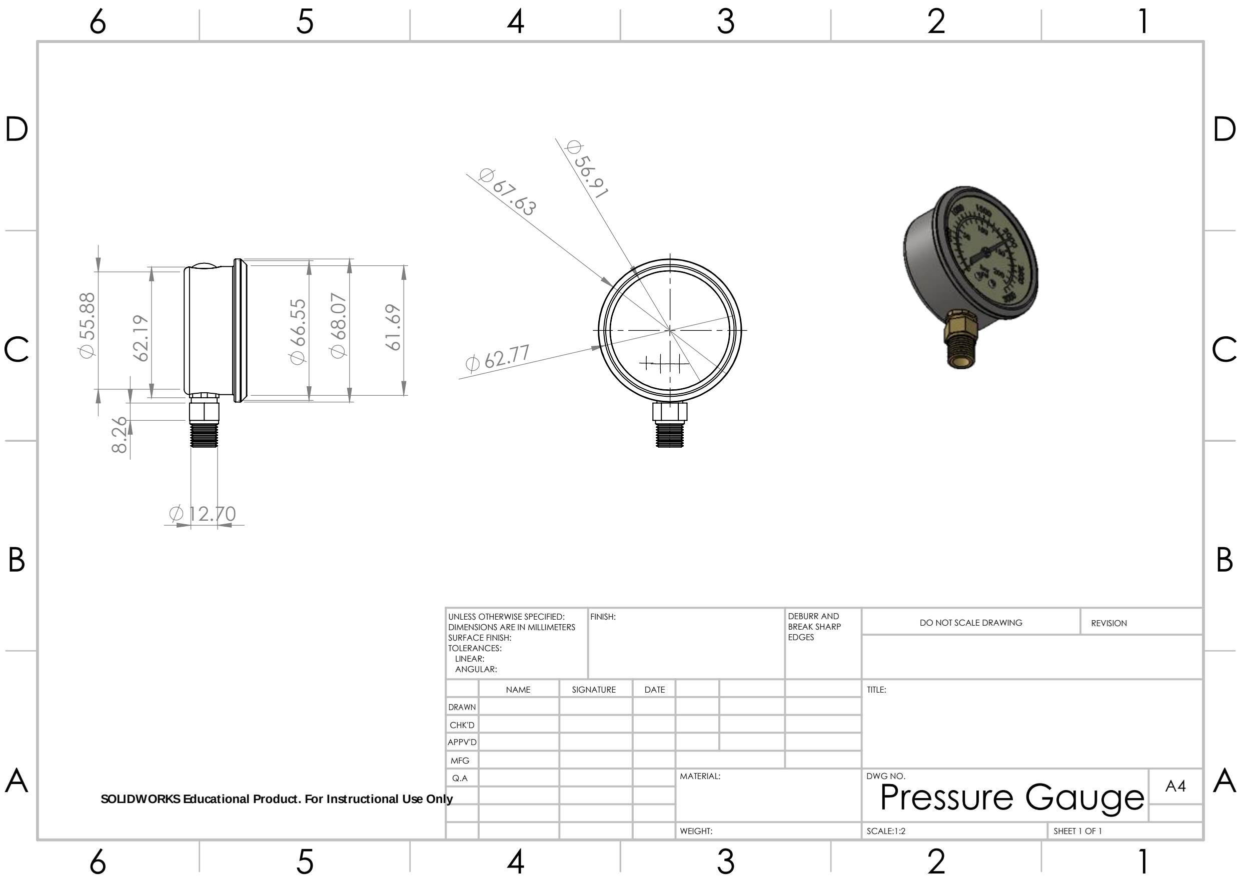
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only


6
5
4
3
2
1
D
C
B
A
9.54
R2
85
77.56
7.58
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
DWG NO.
Plug socket with switches
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only



Ø55.88
62.19
8.26
Ø12.70
Ø66.55
Ø68.07
61.69
Ø67.63
Ø56.91
Ø62.77
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
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WEIGHT:
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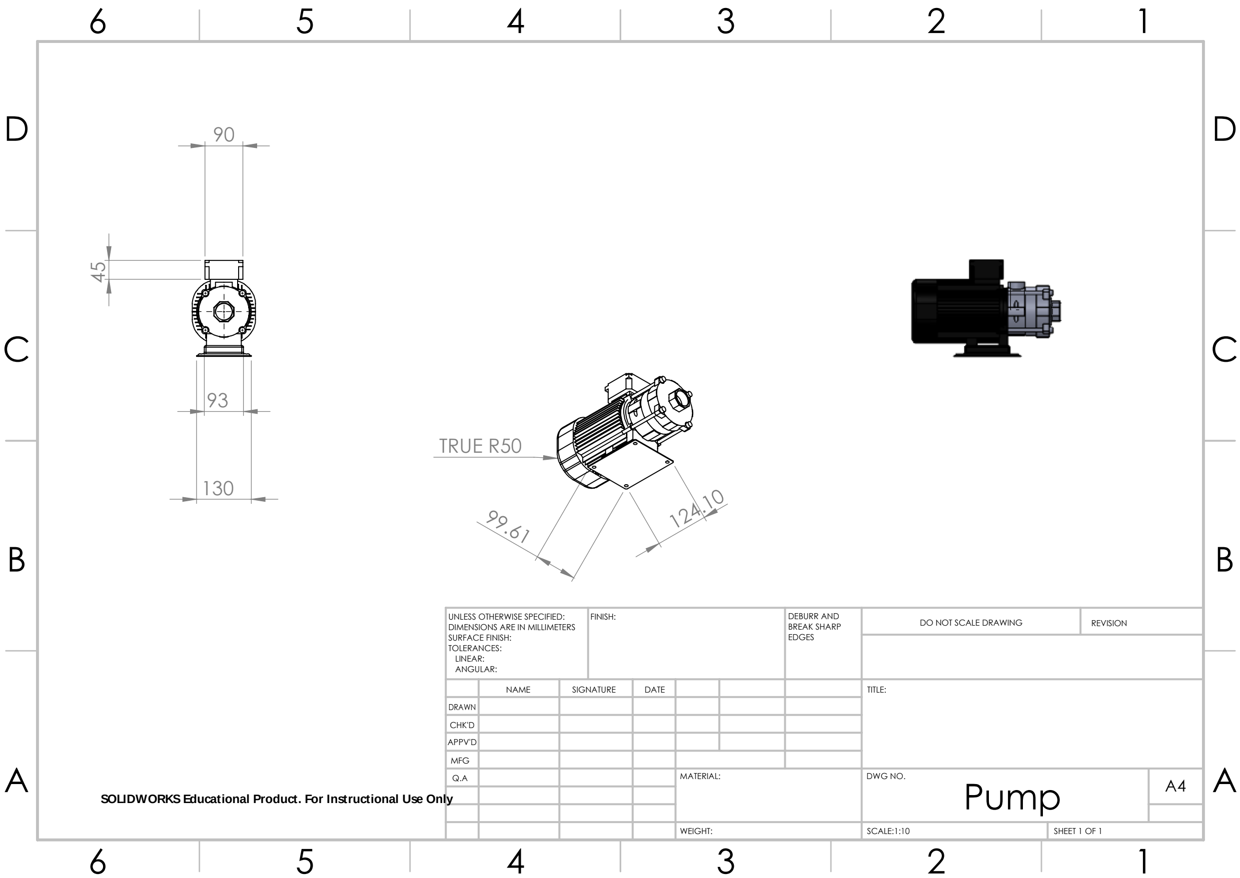
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only


6 5 4 3 2 1
D
C
B
A
90
45
93
130
TRUE R50
99.61
124.10
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
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A4
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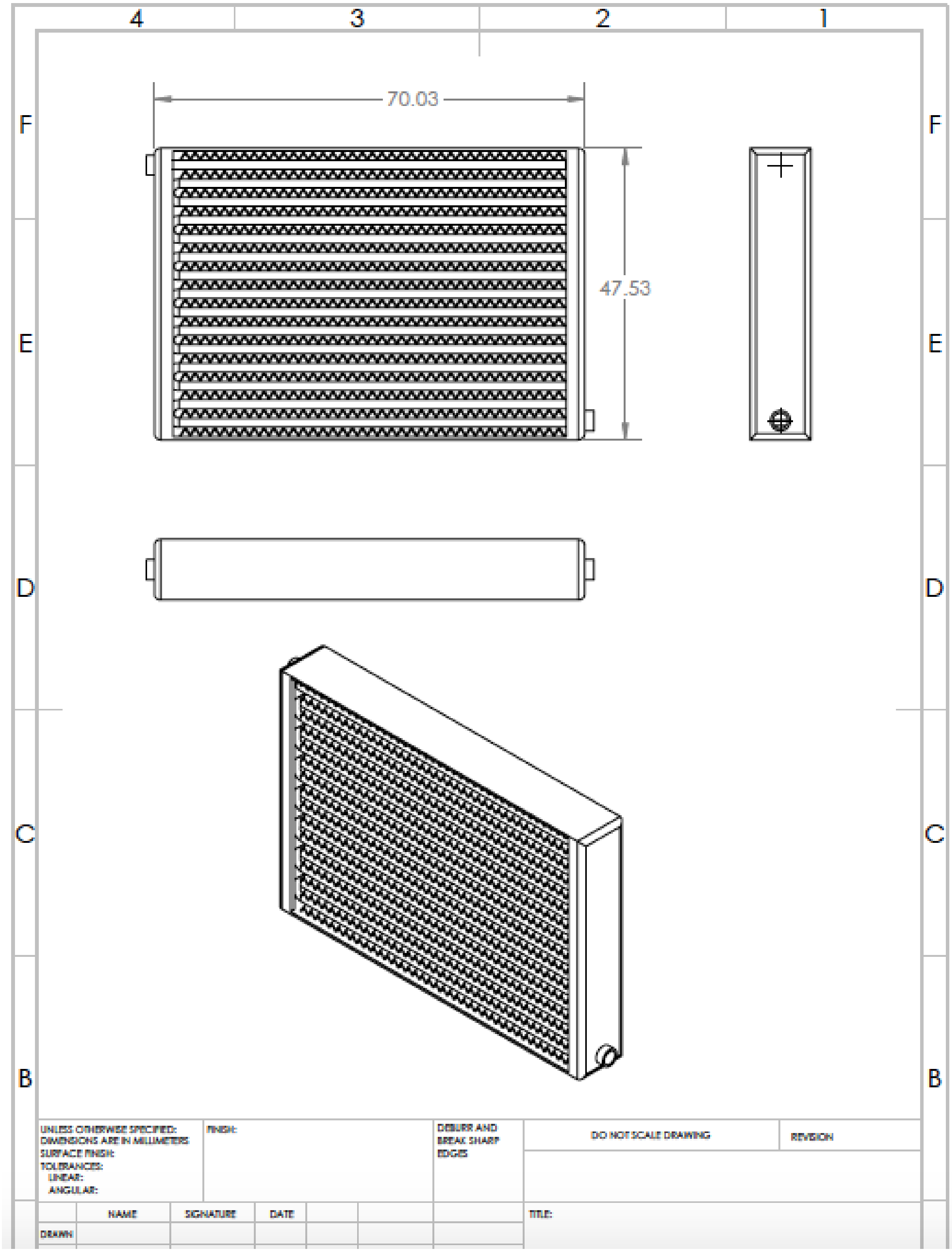
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only


70.03
47.53
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DEBURR AND BREAK SHARP EDGES
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SIGNATURE
DATE
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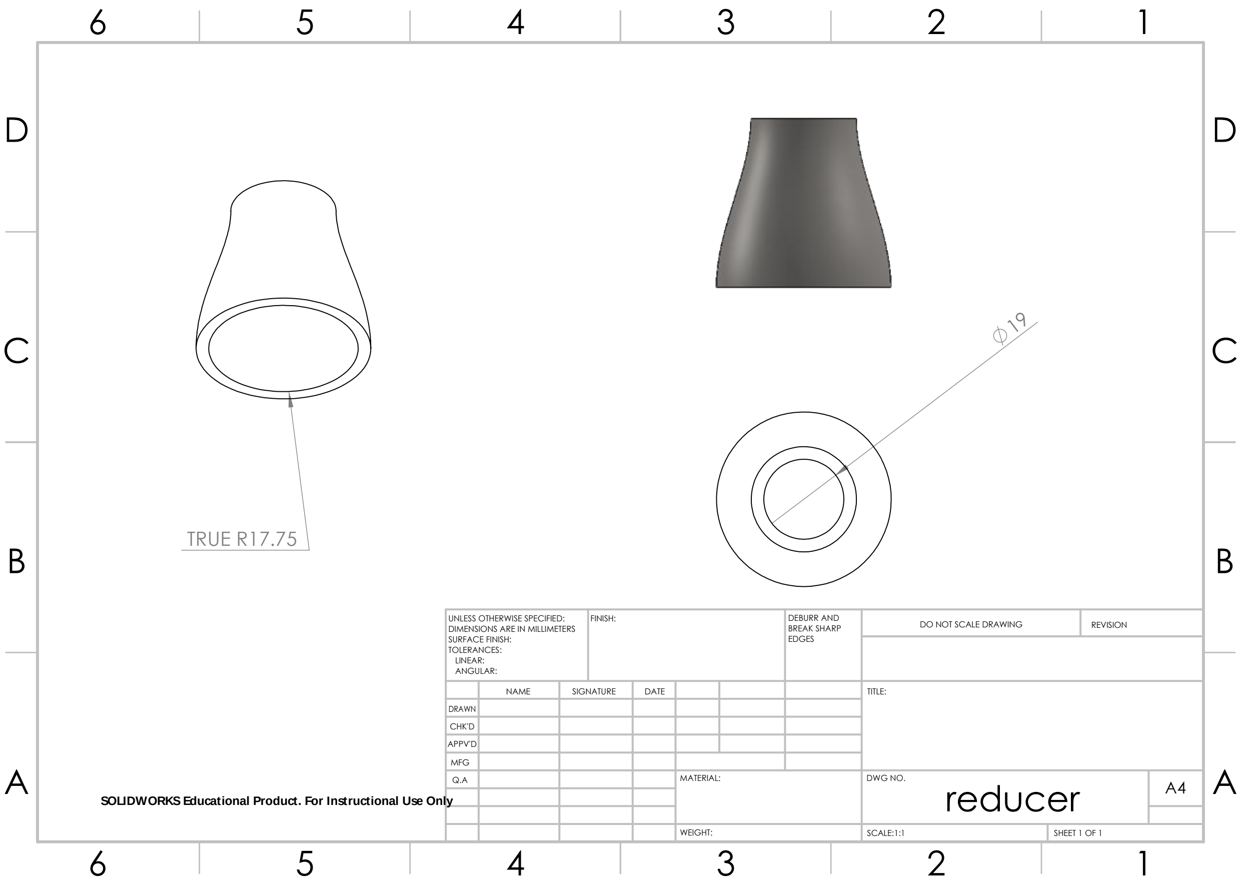
TITLE:


TRUE R17.75
⌀19
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TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
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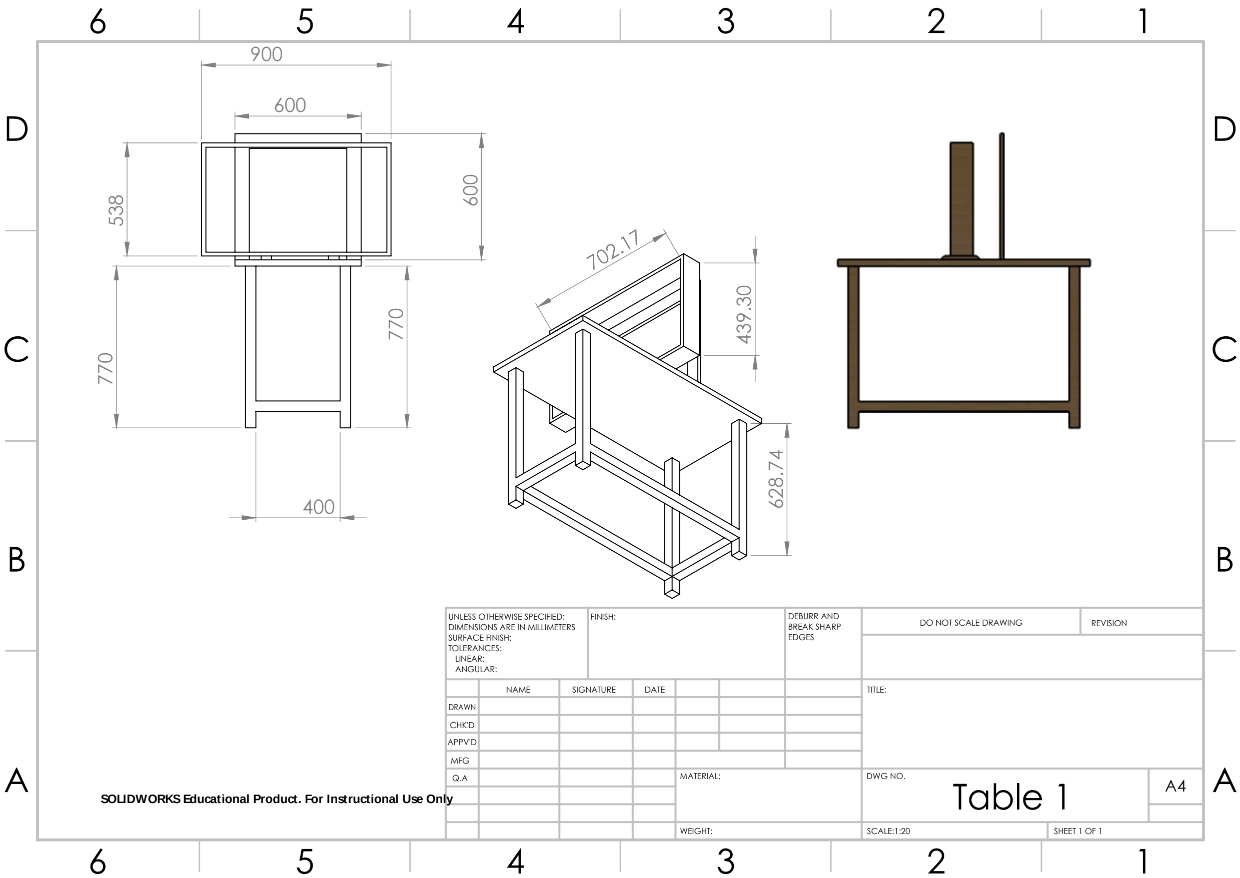
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only


900
600
538
600
770
770
400
702.17
439.30
628.74
UNLESS OTHERWISE SPECIFIED:
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SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
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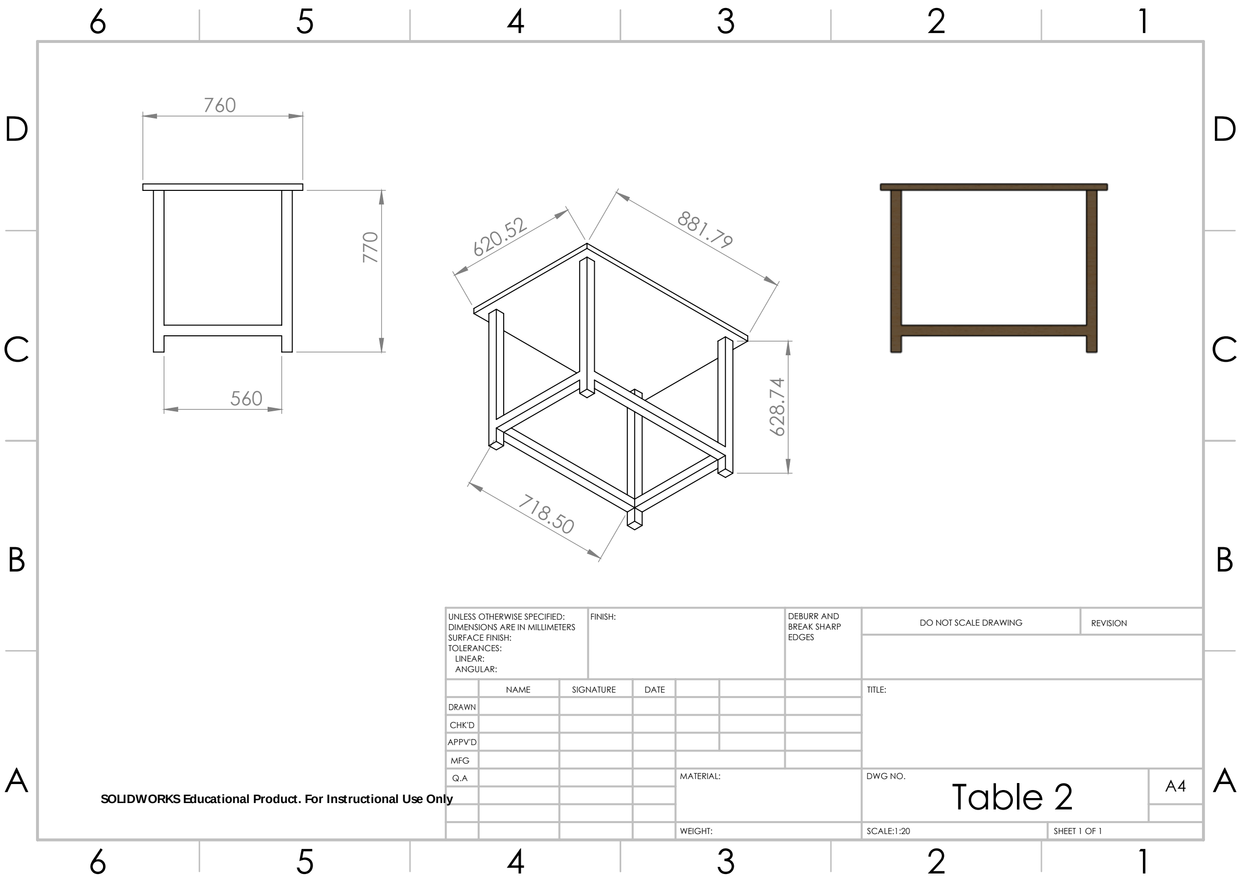
WEIGHT:
SCALE:1:20
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only


760
770
560
620.52
881.79
628.74
718.50
UNLESS OTHERWISE SPECIFIED:
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TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
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WEIGHT:
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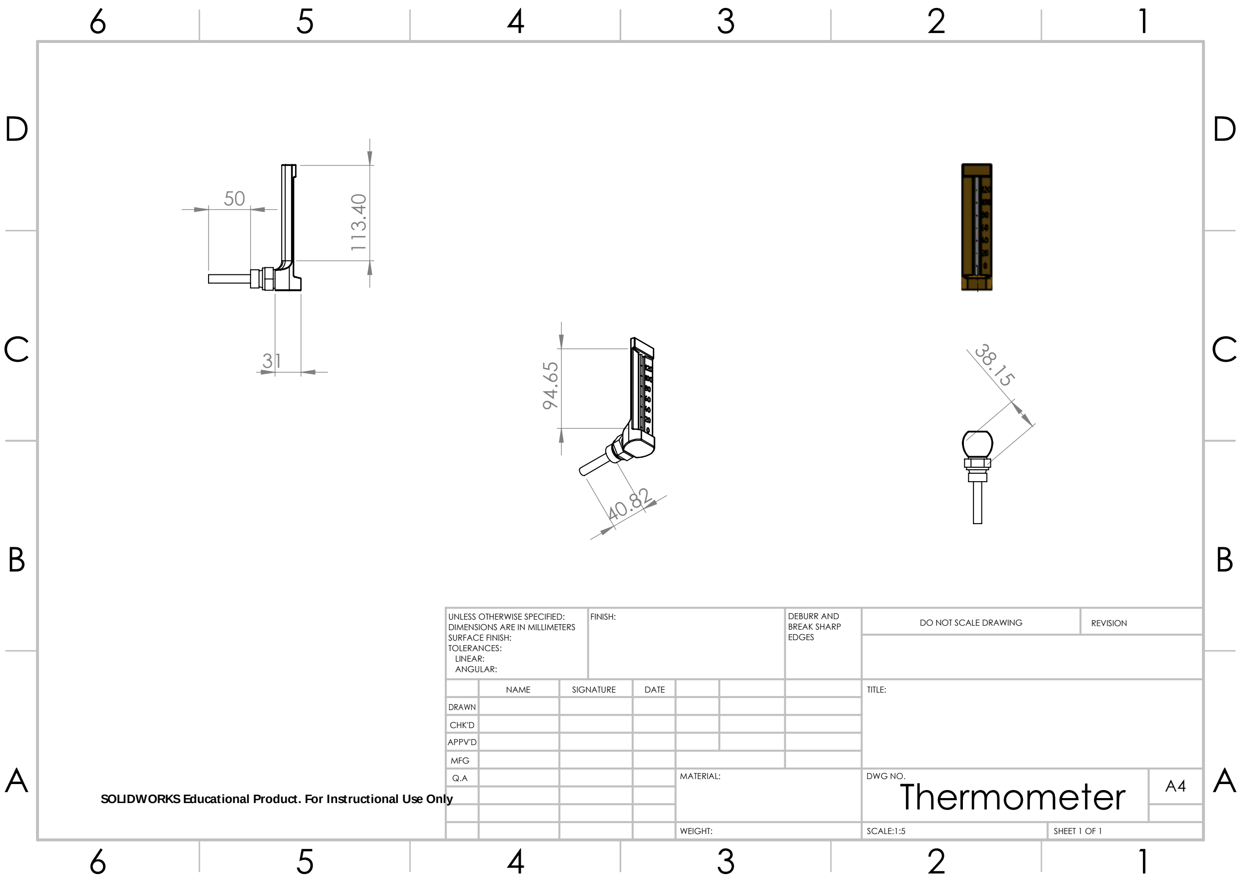
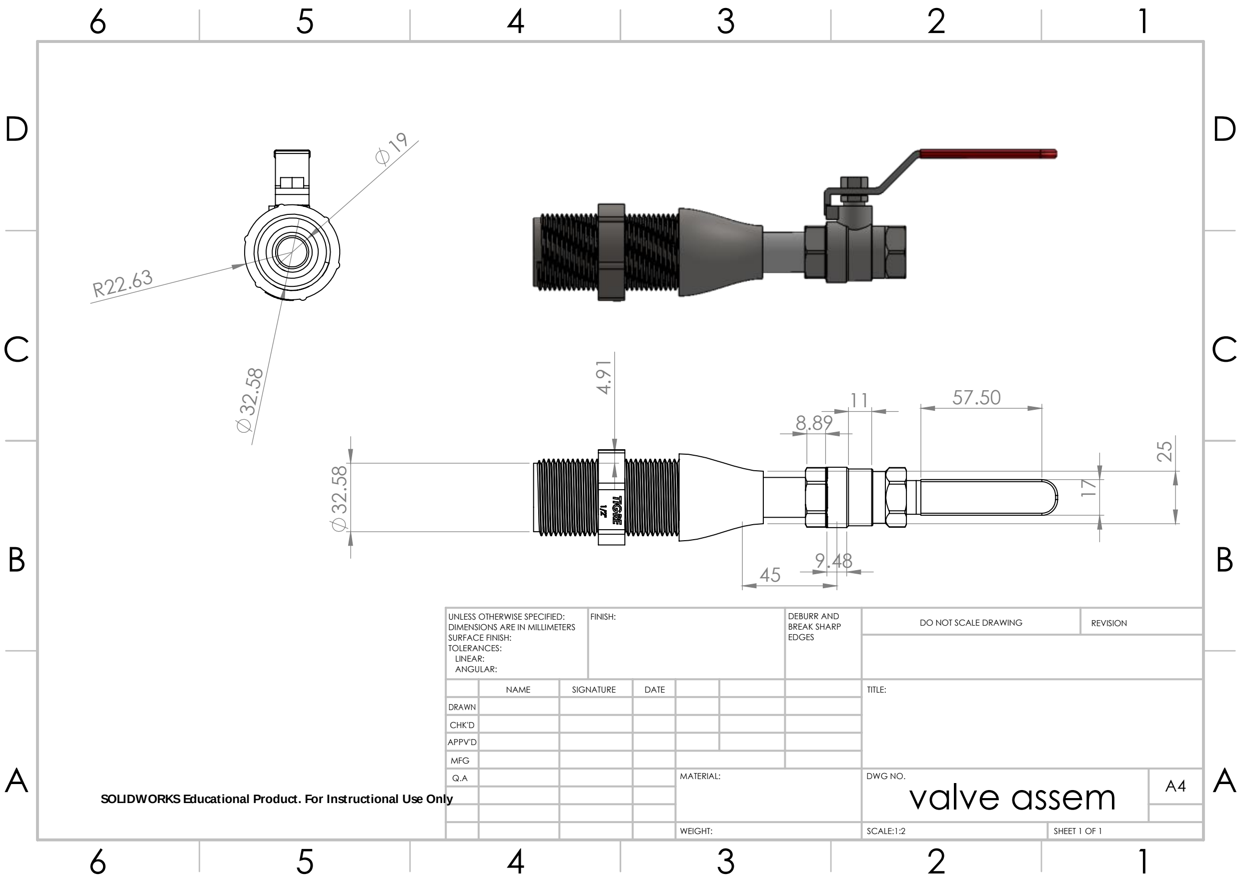
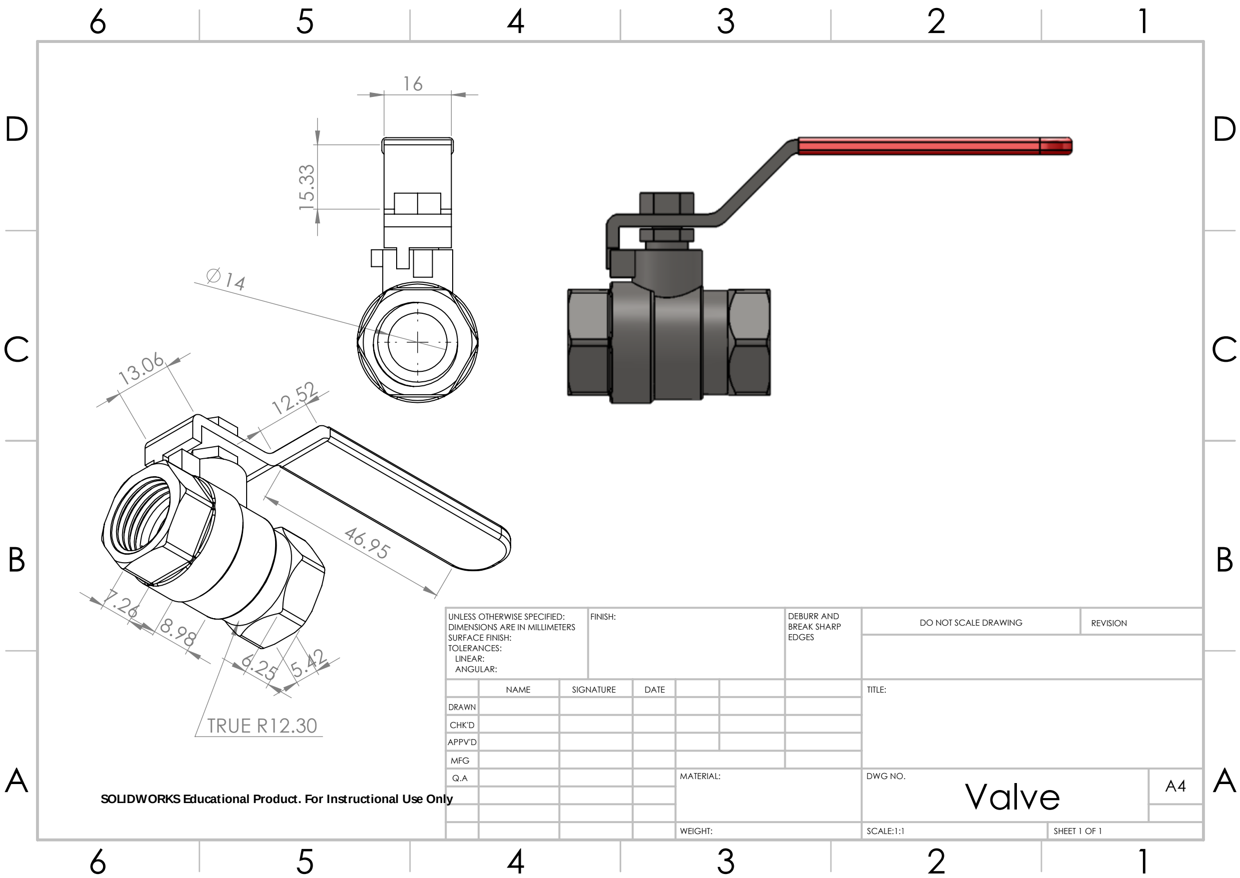
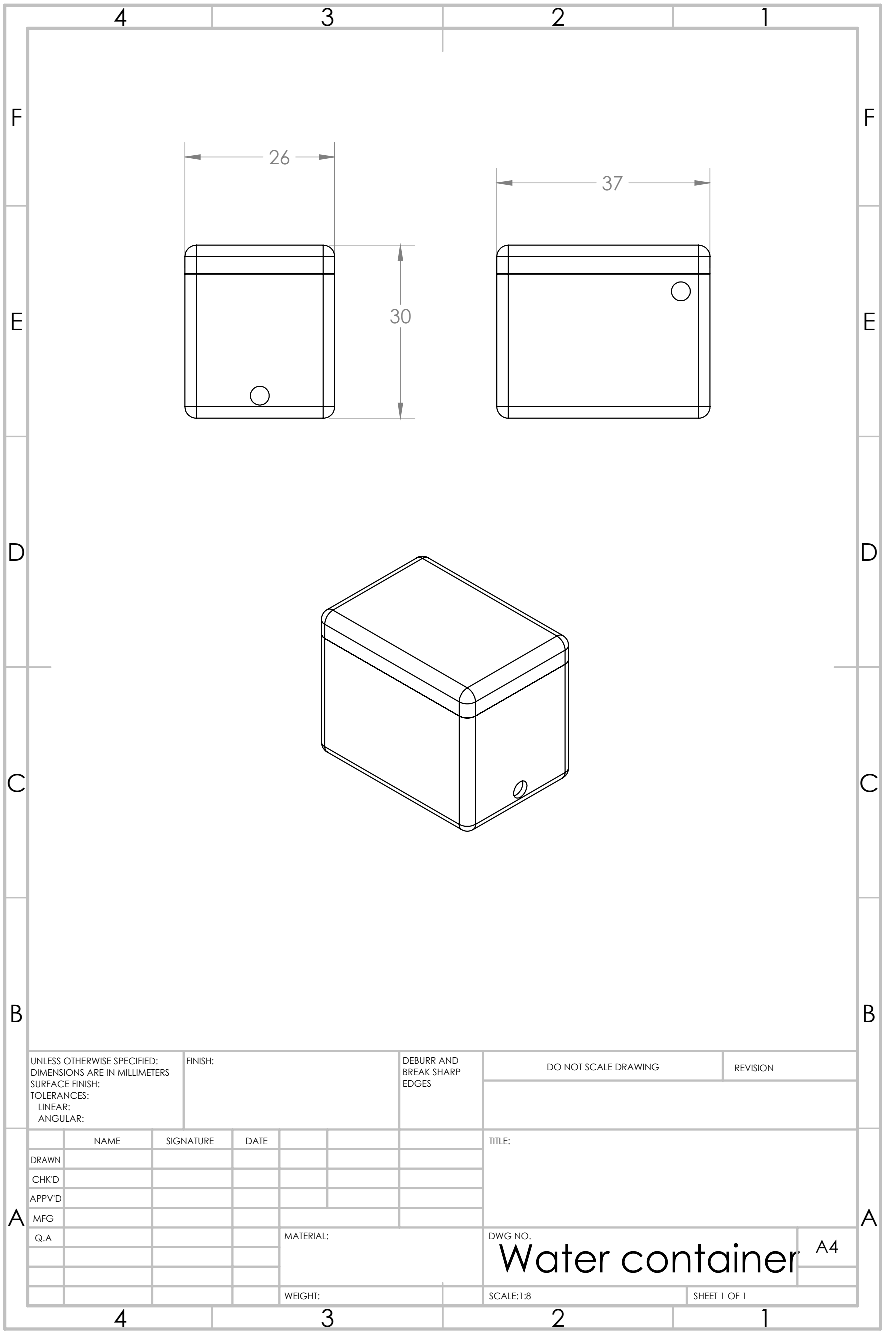
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only


6
5
4
3
2
1
D
C
B
A
50
113.40
31
94.65
40.82
38.15
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
Thermometer
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only


R22.63
Ø19
Ø32.58
4.91
11
57.50
8.89
25
17
Ø32.58
45
9.48
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
valve assem
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only


16
15.33
∅14
13.06
12.52
46.95
7.26
8.98
6.25
5.42
TRUE R12.30
SOLIDWORKS Educational Product. For Instructional Use Only
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
Valve
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1


26
37
30
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FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
Water container
A4
WEIGHT:
SCALE:1:8
SHEET 1 OF 1