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Original Article

Production of 3D scientific instructional models using "ender 3 neo" 3D printer

3D bilimsel eğitim modellerinin "ender 3 neo" 3D yazıcı kullanarak üretimi

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ABSTRACT

It is widely accepted that pupils and students comprehend and retain information more effectively when taught using concrete physical objects. The problem of lack of understanding of the teaching of scientific concepts especially in the secondary schools is partly because the teachers do so by using abstract concepts in teaching science subjects. If a child has not previously seen an object and it is taught without a tangible representation, confusion may arise in the mind of such student. This is where using concrete object becomes important and so the objective of this study is to produce scientific models like skull, eye, brain and skeleton for pedagogic purpose. Although the 3D technology has gained significant recognition worldwide for its ability to produce various equipment, there is limited awareness in developing economies like Nigeria and other African countries; so, this study aims to explore the potentials of 3D printing technology in the production of various scientific equipment for teaching. The methodology used in this research is studio-based and practice-led where 3D printer was used in the studio to produce various scientific instructional models and apparatuses to precision. The models so produced are to be sent to secondary schools for testing and at the end it was found that teaching with physical objects enhancing understanding.

ÖZ

Genellikle öğrencilerin somut fiziksel nesneler kullanılarak öğretildiğinde daha iyi anladıkları ve özümsediklerine inanılır. Özellikle ortaokullarda bilimsel kavramların öğretiminin anlaşılamaması sorunu kısmen öğretmenlerin fen konularını öğretirken soyut kavramlar kullanmalarından kaynaklanmaktadır. Bir çocuğun daha önce görmediği ve böyle bir nesne sağlanmadan öğretilen bir şeyin, öğrencinin zihninde karışıklığa neden olması muhtemeldir. İşte bu noktada somut nesne kullanımı önem kazanmaktadır ve bu çalışmanın amacı pedagojik amaçla kafatası, göz, beyin ve iskelet gibi bilimsel modeller üretmektir. 3D teknolojisi, çeşitli ekipmanlar üretme kabiliyeti nedeniyle dünya çapında önemli bir tanınırlık kazanmış olsa da, Nijerya ve diğer Afrika ülkeleri gibi gelişmekte olan ekonomilerde sınırlı farkındalık vardır; bu nedenle bu çalışma, öğretim için çeşitli bilimsel ekipmanların üretiminde 3D baskı teknolojisinin potansiyellerini keşfetmeyi amaçlamaktadır. Bu araştırmada kullanılan metodoloji stüdyo tabanlı ve uygulama odaklı olup, stüdyoda hassas bir şekilde çeşitli modeller ve aparatlar üretmek için 3D yazıcı kullanılmıştır. Bu şekilde üretilen modeller test edilmek üzere ortaokullara gönderilecek ve sonuçta fiziksel nesnelerle öğretimin anlayışı geliştirdiği görülmüştür.

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INTRODUCTION

Cano (2015) observes that the term 3D printing covers a lot of processes and technologies that are used for the production of various materials ranging from auto parts to beef, human parts and plastic products. Essentially, what is common amongst the various techniques is that production is carried out layer by layer in an additive manner which is at variance with the traditional methods of production using the subtractive, sculpting and casting processes. Applications of 3D printing processes keeps evolving almost on a daily basis, and as this technology continues to permeate more deeply across industrial circles, awareness is created. Ford and Minshall (2018) avers that today, the world has only just begun to witness the true prospect of 3D printing.

Fundamentally, the unique theory that drives 3D printing is that it is an additive manufacturing process; and this is indeed the nucleus of this study in the sense that 3D printing is a completely different manufacturing process that is hinged on advanced artificial intelligence robotic technology that build up various parts of products in an additive manner using layers in minute scales which is not the same with other techniques. Lipson and Kurman (2013) advanced the disadvantages in the conventional building that has essentially been built on handmade patterns.

Many authors have written various books and materials about what 3D printing and additive manufacturing is essentially about but the efforts of this writers show a particular step-by-step manual of the production processes of scientific instructional materials like skeletons, the heart model, skull and other anatomical structures. Teaching of science subjects like Biology is easier handled with the use of concrete teaching apparatuses. And that is what this research is all about. In the light of the foregoing, this research seeks to delve into the unexplored domain of 3D printing of scientific models which, in the interim could be used as instructional materials in the teaching of science-based subjects like Biology. This research aims to pave a way for informed strategies that promote the integration of 3D printing within the confines of the creative landscape of Graphics. Through this exploration, this research aspires to contribute to the enrichment of artistic and scientific legacy, while simultaneously positioning various countries involved in it as the vanguard of technological innovation in the sciences, arts and design.

Statement of the Problem

Since the onset of the global recession, scientific instructional models have become difficult to procure from foreign manufacturers with the rise in the purchase of foreign exchange; moreover the models acquired by various institutions have become old and in a state of disuse and so, local production of these models has become a necessity and as graphic artists, these researchers have taken the initiative to produce these materials without further consulting foreign manufacturers; this will save cost and promote indigenous technology.

Aim and Objectives of the Study

This study aims to produce scientific instructional materials for use in the teaching of Human Biology in Nigerian secondary schools and other research institutes. While the objectives are as follows:

i. Gather data to know the state of use of scientific instructional materials in selected secondary schools in Nigeria.
ii. Query the barriers, challenges, and factors that hinder the use of scientific instructional models in these schools
iii. Produce these models
iv. Distribute to schools to test their effectiveness as instructional materials

MATERIALS AND METHODS

The methodology employed in this research is studio-based and practice-led where 3D printer was used in the studio to produce various models and apparatuses. Materials like 3D printer and different types and grades of filament and portable electric generating set were purchased to facilitate the seamless outcomes of this research as 3D printing technology has been found to save time and produce materials with precision and so at the end of this research, the models manufactured were used as instructional materials for the teaching of science students and for use in medical research institutions.

Tools and materials employed in the production.

1. Ender 3 Neo 3D Printer
2. White unbranded filament (Diameter 1.75 mm)
3. Prusa Slicer 2.7.4

These scientific instructional models were done using the Fused Deposition Modeling (FDM) method of 3D printing. The items produced are one complete structure of human skeleton, a skull and the heart vessel. Ahmad et al (2019) are of the view that 3D printing technology is useful in the area of dentistry for producing various types of teeth and in the same vein, these researchers, in carrying out this production took several steps; from the preparation of the digital model to post-processing of the printed parts were done and below are the production steps:

The first step was to obtain a 3D Model, the items were acquired from Creality.com. Creality is an online repository where 3D Models can be purchased while other online repositories are, Thingiverse, GrabCAD and PursaSlicer.

Secondly, the model was sliced using slicer software known as PrusaSlicer 2.7.4. Slicing is a crucial step in the 3D printing process, as it directly affects print quality, accuracy, and efficiency. In 3D printing technology, Horvath and Cameron (2020) sees “slicing” as the process of dividing a 3D digital model into thin, horizontal layers or slices. This is done to prepare the model for printing, as 3D printers create objects layer after layer as seen in Figure 1.

The model of the skeleton was imported into PrusaSlicer Slt format. Slt is a file format used to represent 3D models, specifically designed for stereolithography (SLA) and resin 3D printing. It contains information about 3D model’s

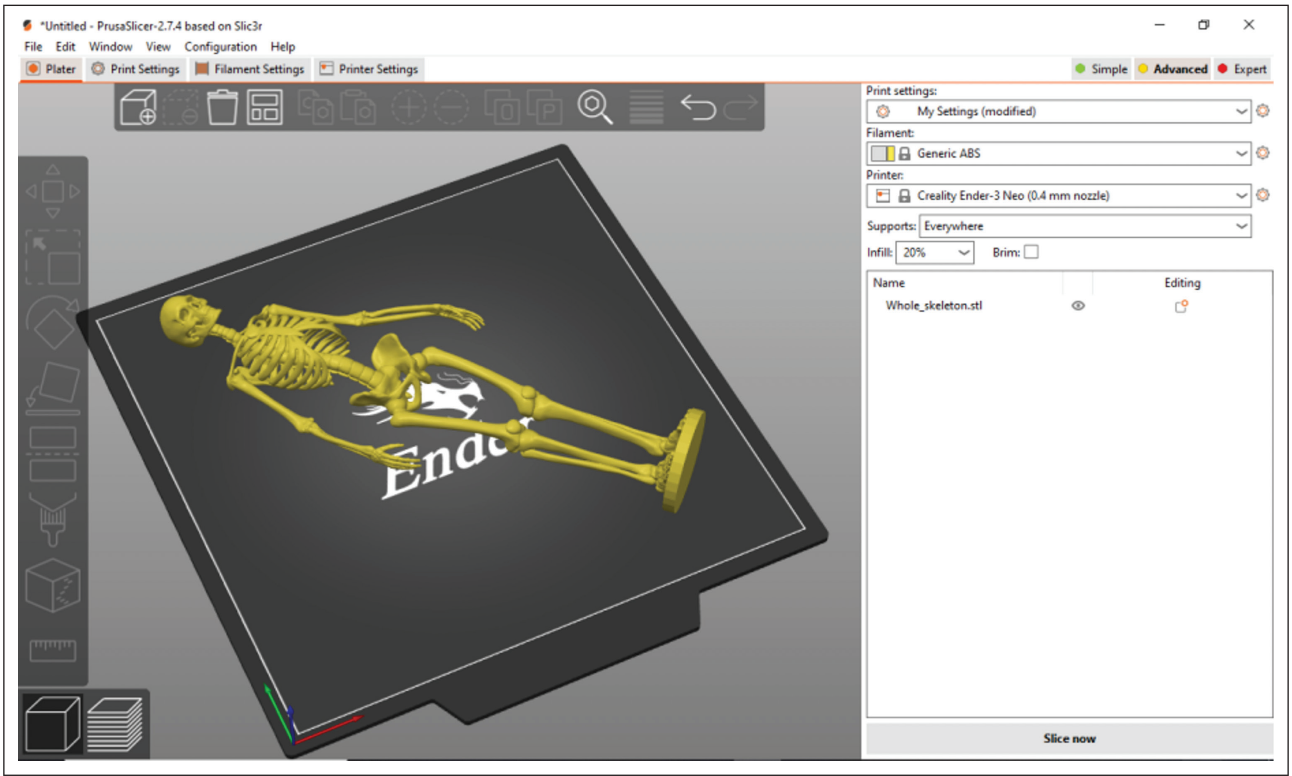

Figure 1. PrusaSlicer showing a model of skeleton (screenshot by Onosigho, B.O. & Osaigbovo, F.O.).

geometry, including the triangles that make up the model's surface, as well as layer information for printing. The dark square area where the skeleton lies is a simulation of the print bed area whose area is 220 mm by 220 mm.

The purposes of slicing as submitted by Prusa & Bach (2019) are as follows:

i. To change 3D models into printable format: Slicing software converts the 3D model into a format the 3D printer understands.
ii. To generate print paths: Slicing creates the print paths for the 3D printer to follow, ensuring accurate and efficient printing.
iii. To determine layer height and thickness: Slicing software sets the layer height and thickness, which affects print resolution and speed.
iv. To optimize print settings: Slicing allows for optimization of print settings, such as infill density, support material, and print speed.
v. To prepare for print bed adhesion: Slicing ensures proper adhesion to the print bed, thereby preventing warping or detachment during printing.
vi. To estimate print time and usage of material: Slicing provides estimates of print time and usage of material, helping with planning and resource allocation

The green part in Figure 2 above shows the grid support style of structure; those parts are removable after the printing is completed. The brown colour of the skeleton of the image above is the default colour of all models imported into the slicer application and will not be the same as the final output whereas output colours will be dependent on the colour of the filament loaded in the printer. After the above, perimeters in 2.0 was set for optimized printing as shown below in terms of the height, infill density, print speed, and support structures, the model was sliced simply by clicking on the slice button. The software automatically slices the model and the result can be seen visually in Figure 2 which is saved in G-code.

3D Printer Settings for Production of the full Skeleton

Layer/Perimeters:
Layer height – 0.3 mm
First layer height – 0.35
Vertical shell – 3 mm
Horizontal shell top – 3 mm
Horizontal shell bottom – 3 mm
Seam position – Aligned

Support Material:
Support style – Grid
Top contact z distance – 0.2 (detachable) mm
Bottom contact z distance – 0.2 (detachable) mm
Support pattern – Rectilinear
Pattern spacing – 2.5mm
Top interface layers – 3 (heavy) mm
Bottom interface layers – 3 (heavy) mm
Interface pattern – Rectilinear
Interface pattern spacing – 0mm
XY separation between an object and its support - 50°

Speed:
Perimeters – 60 mm/s
Small perimeters – 15mm/s
External perimeters – 50% mm/s
Infill – 80 mm/s
Solid infill – 20 mm/s

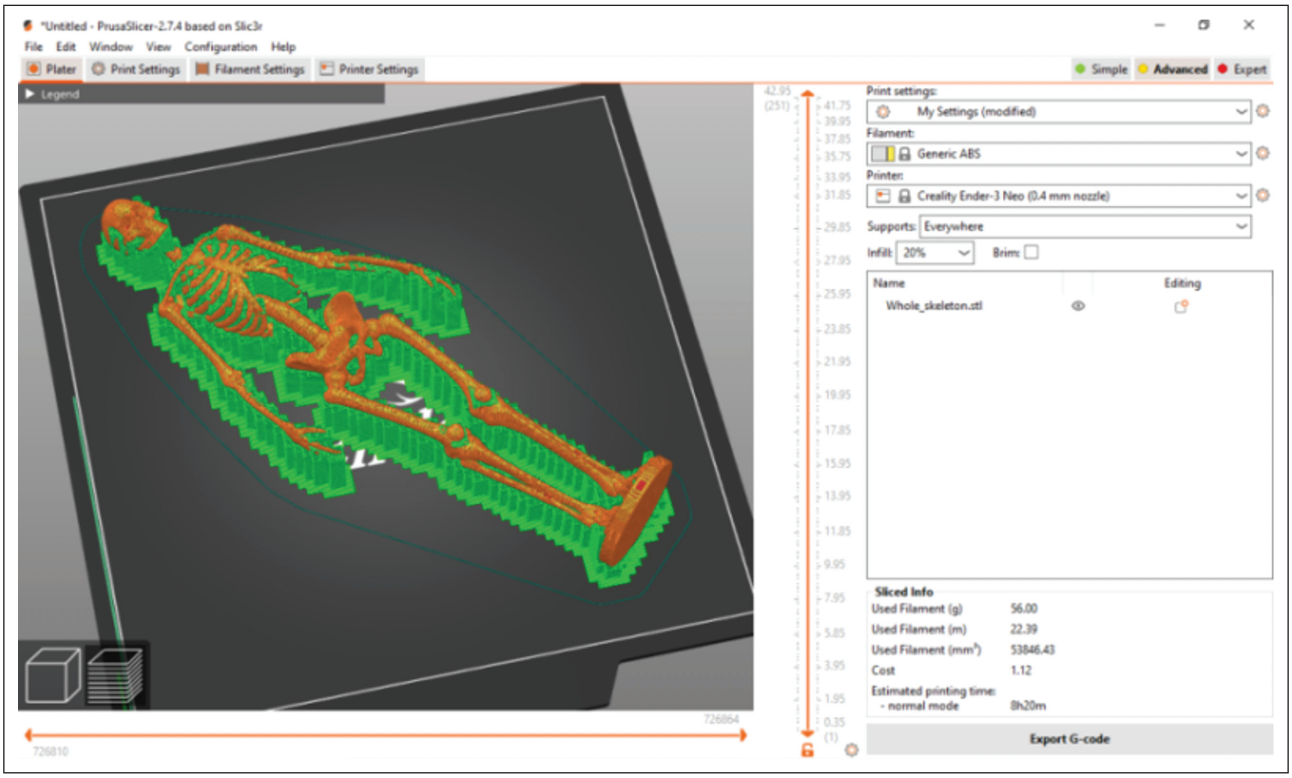

Figure 2. PrusaSlicer showing s model of skeleton with support (screenshot by Onosigho, B.O. & Osaigbovo, F.O.).

Top solid infill – 15 mm/s'
Support materials – 60 mm/s
Bridge – 60 mm/s
Gap fill – 20 mm/s
Speed for non-print moves
Travel – 130 mm/s
Z travel – 0 mm/s
Modifiers
First layer speed – 30 mm/s

The setting used for printing the skeleton in Figure 3 was also used to print two other models, a skull and the heart model. Below are the objects as at when they were imported into PrusaSlicer for slicing. The settings are not uttered most times except when there is change of material from PLA to ABS or PETG. Another reason that could make for resetting is only if the structure of a model changes and so it is not all models that needs support.

Figure 4 is the heart model in the Prusa Slicer environment. The screen above shows a detailed breakdown of the printing time. Located at the top-left corner of the viewport is a transparent layer labeled "Legend" as seen in Figure 4. On the legend is the feature type which carries the breakdown of the time it will take to print the different parts of the model after being sliced. Table 1 below is the breakdown according to the parts that make up the model as displayed in Figure 4. The green area in Figure 5 are the support holding the overhangs in place, those parts were removed during the post-processing phase.

Figure 3. 3D printed full skeleton after support has been removed (screenshot by Onosigho, B.O. & Osaigbovo, F.O.).

Figure 6 reflects the white colour of the PLA filament used for the printing. These are the results after the post-processing stage. After slicing, the colour of models turns from gold to orange with the support areas green as it shown in the screenshot in Figure 7. The skull model in Figure 8 was imported into PrusaSlicer and awaiting slicing, that is why the colour is gold. The setting used for the skel-

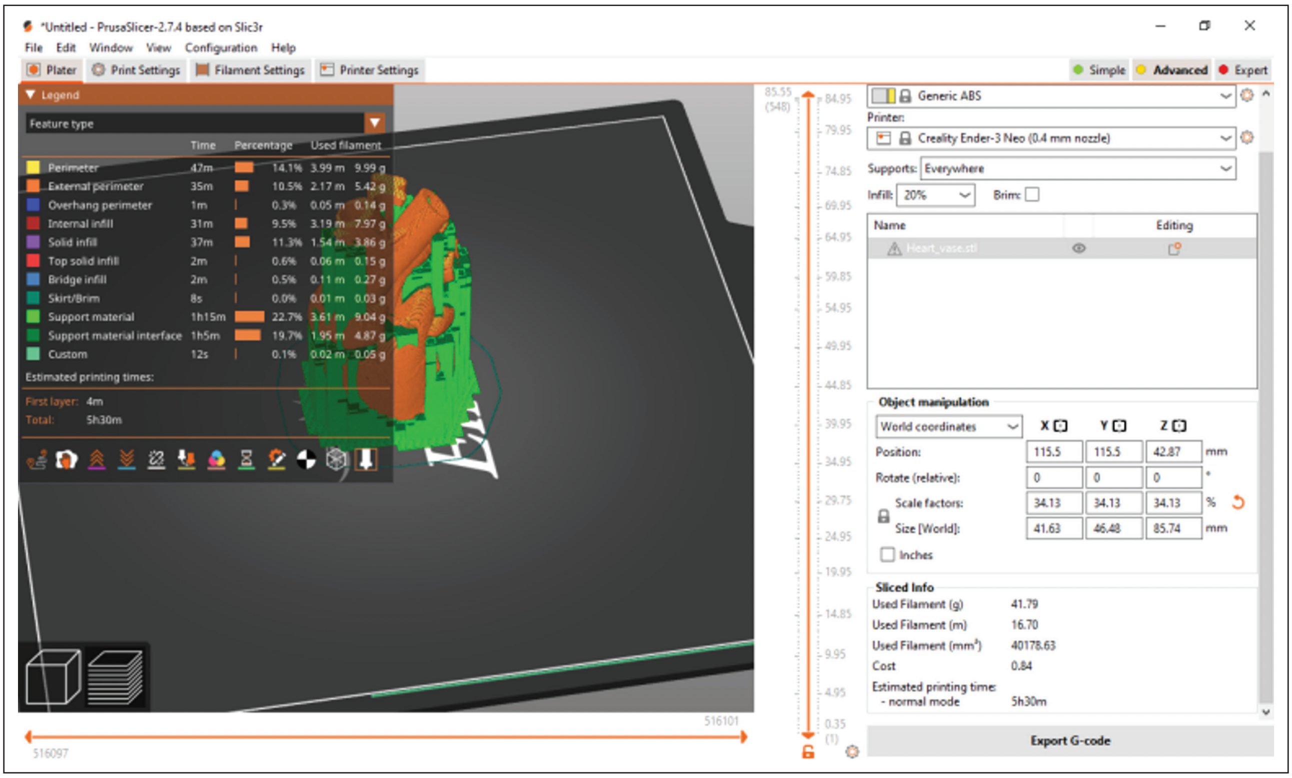

Figure 4. 3D printed full skeleton after support has been removed (screenshot by Onosigho, B.O. & Osaigbovo, F.O.).

Table 1. Estimated printing time is 5 hrs 30 m

Feature type	Time	Percentage	Used filament
Perimeter	47 m	14.1%	3.99 m 9.99 g
External perimeter	35 m	10.5%	2.17 m 5.42 g
Overhang perimeter	1 m	0.3%	0.05 m 0.14 g
Internal infill	31 m	9.5%	3.19 m 7.97 g
Solid infill	37 m	11.3%	1.54 m 3.86 g
Top solid infill	2 m	0.6%	0.06 m 0.15 g
Bridge infill	2 m	0.05%	0.11 m 0.27 g
Skit/brim	8 s	0.0%	0.01 m 0.03 g
Support material	1 h 15 m	22.7%	3.61 m 9.04 g
Support material interface	1 h 5 m	19.7%	1.97 m 4.87 g
Custom	12 s	0.1%	0.02 m 0.05 g

eton model and heart model was retained since the output of the skeleton was okay. Figure 9 is a printed skull using white filament.

Preparation of the printer was the next step and selection of material is very important at this stage; PLA (Polylactic Acid) filament was selected because of the ease of printing as compared to ABS and PETG which are more difficult to print although they are more durable especially when printing outdoor objects that will be having direct contact with the atmosphere. PLA (Polylactic Acid) is a biodegradable thermoplastic commonly used in FDM 3D printing due to its ease of use and good print quality; this assertion was corroborated by Ford and Minshall (2018) who stressed that PLA was best for amateurs that are learning to keep pace with 3D printing technique as it is normally used for educational models due to its ease of production and usage. White filament was chosen and loaded on the just to mimic the actual colour of bones and the diameter of the filament was 1.75 mm.

The next step was calibration of the printer; this process involves leveling of the print bed and nozzle height adjustment, followed by the printing process while the printing was monitored especially for the initial layers to ensure proper adhesion and adjust settings if necessary. It took a total 8 hours and 20 minutes from the first print layer to the last on top on the Z axis.

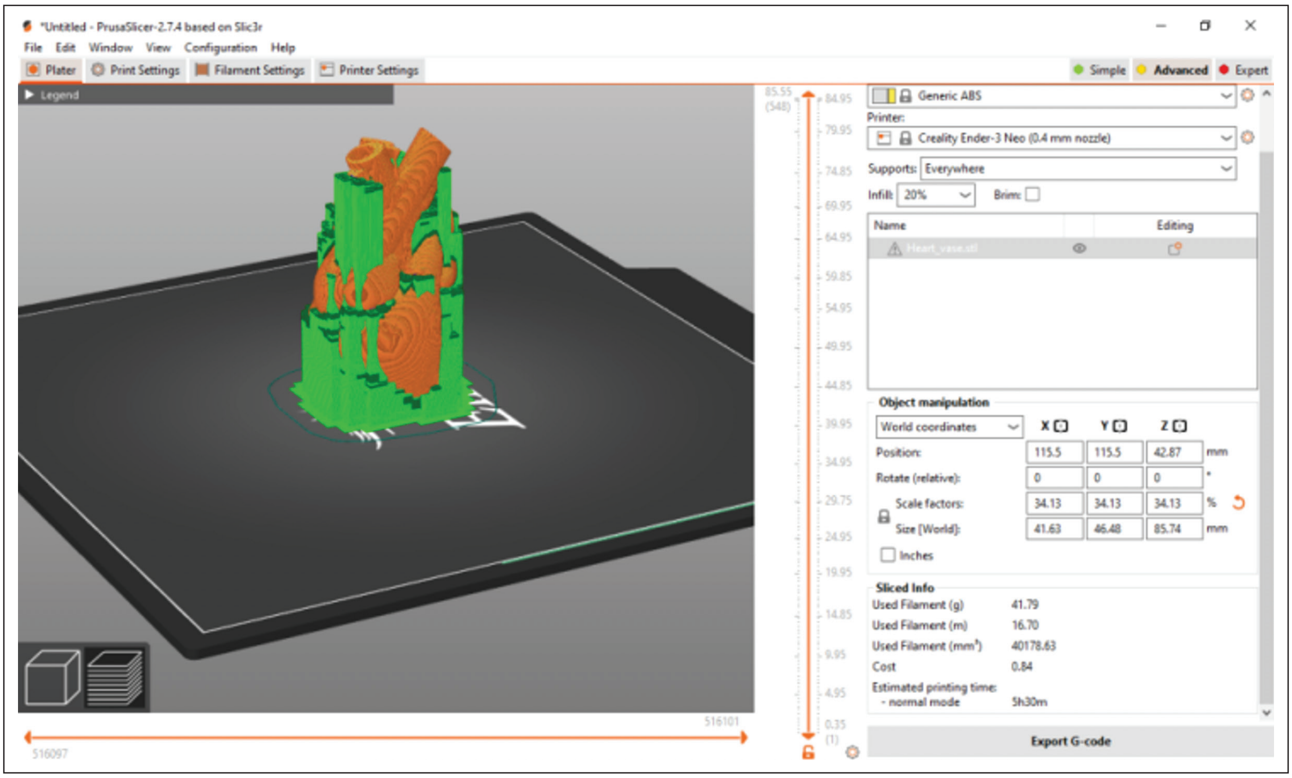

Figure 5. PrusaSlicer showing a model of heart with support material (screenshot by Onosigho, B.O. & Osaigbovo, F.O.).

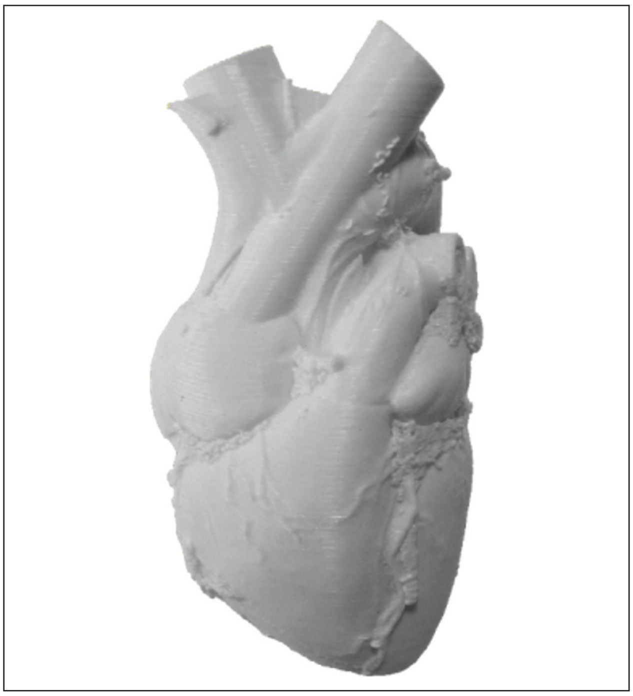

Figure 6. The Heart model after support has been removed (screenshot by Onosigho, B.O. & Osaigbovo, F.O.).

Spahic (2020) refers to the last stage as post-processing stage and at this point the supporting structures were all removed using tools like pliers, cutters, and hobby knives; after removing all support structures, the object was checked to ensure that no part was mistakenly removed in the course of the removal of the supporting structures.

Other activities involved in the post-printing stage are sanding and smoothing of rough surfaces especially when acrylic paint finish will be applied. But the finishing of the skeleton was quite impressive, so there was no need for gloss finishing.

Description of the Software Environment

The PrusaSlicer 2.7.4 version is popular slicing software for 3D printing and its window for 3D objects consists of several key sections as seen in Figure 10. There are other slicing software that could have been employed for this project, however, PrusaSlicer was chosen because it is one of the most popularly used and its slicing environment when compared to the others like Creality and Cura, contains more details in the settings for beginners and experts which makes it the choice of most 3D printing enthusiasts. Figure 10 shows the environment of PrusaSlicer application.

Some Highlights of the Software Environment

i. **Software Name:** At the top-most section when the software is lunched is the name and version of the software.
ii. **Menu Bar:** The menu bar is located just below the software identification and version at the top. This is the section where menus like the File, Edit, Window, View, Configuration and Help are located. And there are actions that can be taken under each menu. For example, under the file menu, actions such as: New Project, Open Project, Recent Projects, Save Project, Save Project as …, Import, Export, Convert, Eject SD Card/Flash Drive, (Re) Slice Now, Repair Stl file, G-code Preview and Exit.

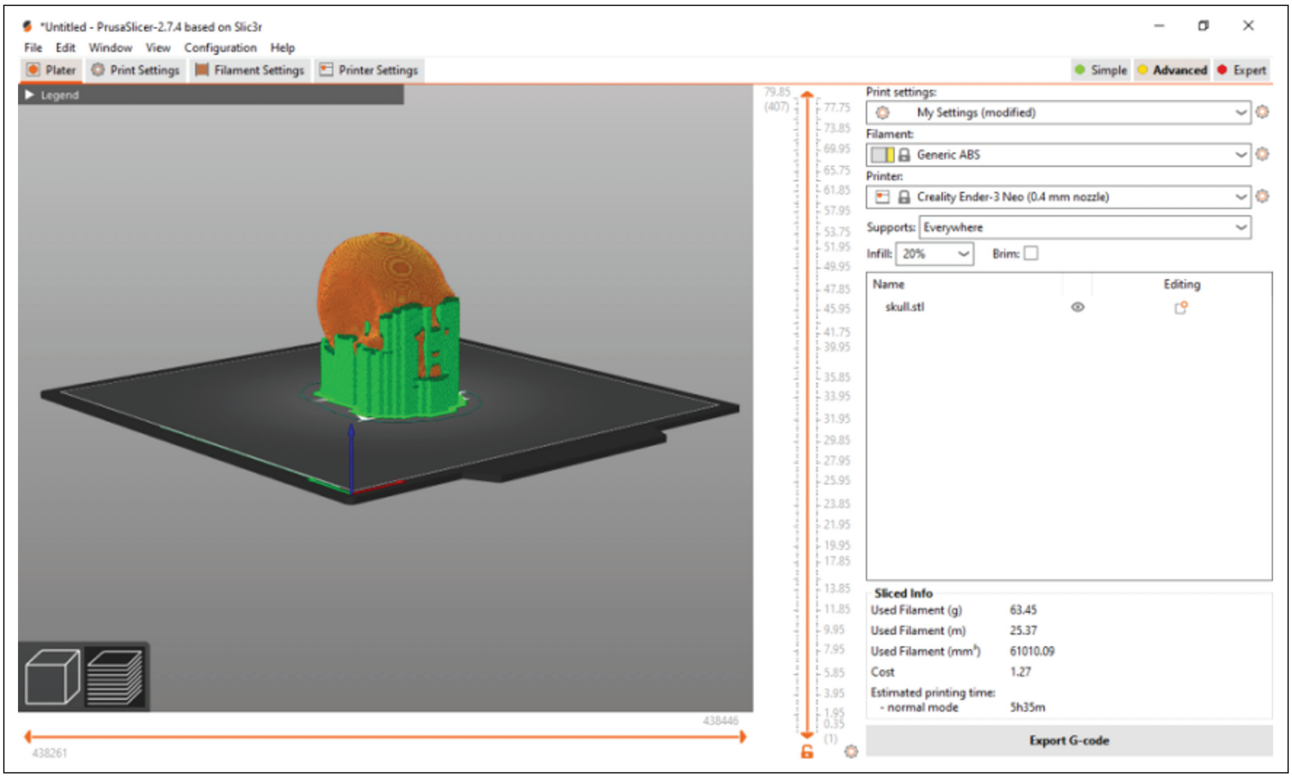

Figure 7. PrusaSlicer showing s model of a skull (screenshot by Onosigho, B.O. & Osaigbovo, F.O.).

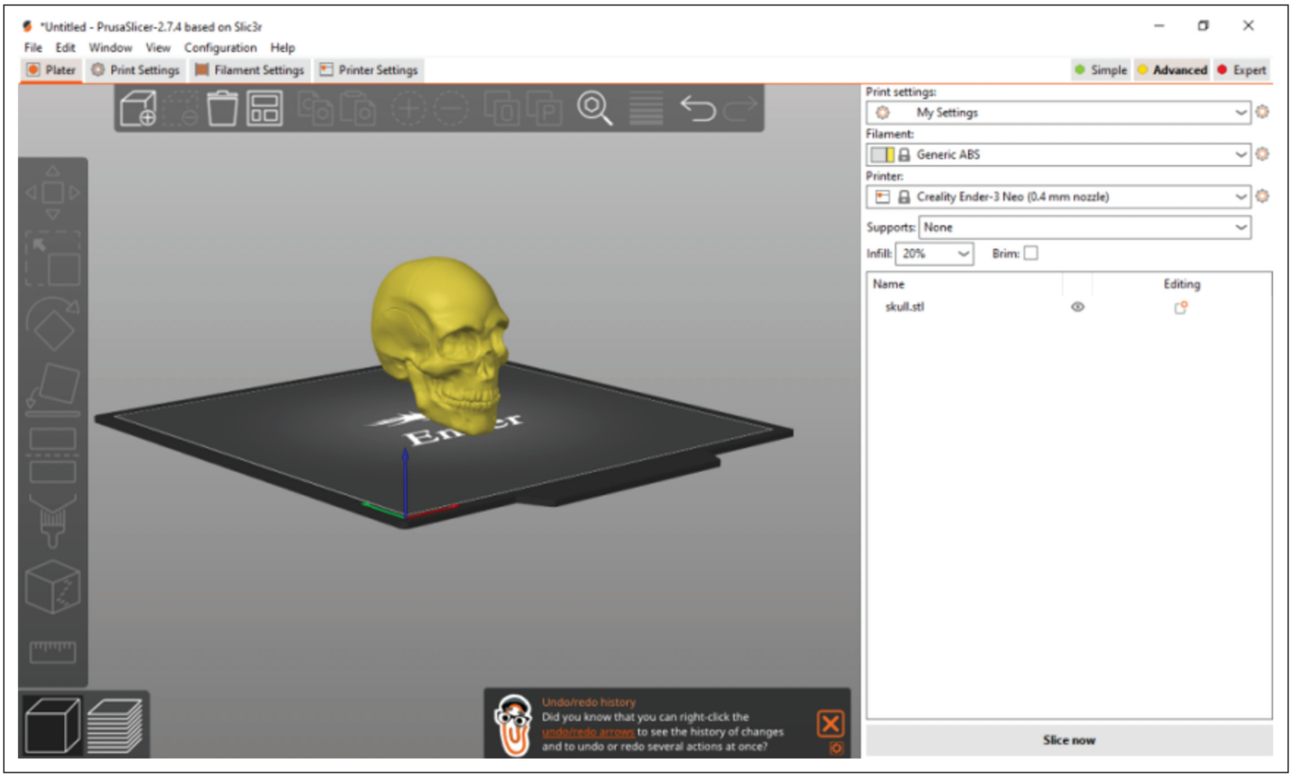

Figure 8. PrusaSlicer showing s model of a skull (screenshot by Onosigho, B.O. & Osaigbovo, F.O.).

iii. **Toolbar:** This is located directly below the menu bar. The toolbar provides quick access to common actions such as Plater, Print Settings, Filament Settings and Printer Settings.

iv. **3D Viewport:** This is the main area where the 3D object is displayed, allowing for rotation, zooming, scaling and panning.

v. **Icon:** A sidebar showing a list of loaded objects, their names, and properties.

Figure 9. Finished result of the skull after the supports has been removed (screenshot by Onosigho, B.O. & Osaigbovo, F.O.).

vi. **Setting Panel:** A tabbed section for configuring slice settings such as layer height, infill density and support materials.
vii. **Slice Preview:** A 3D representation of the sliced objects showing individual layers and the print paths.
viii. **Console:** A log area displaying messages, warnings and errors during slicing and printing.
ix. **Status Bar:** At the bottom-most section is status bar showing information such as object dimensions, slice time and estimated print time.

Within these sections, other actions can also be performed such as:
Loading and manipulating 3D models
Configuring slice settings and print parameters
Preventing and adjusting slice layouts
Exporting G-code for printing.

At a glance on the work environment is a set of menu bars at the top-most section of the screen. Underneath the menu bar is the viewport. At the top and at the left-end of the viewport are sets of icons that get activated when a model is imported into the software. At the right side of the screen is where the three categories of settings are displayed. The amount of modification that can be made in a model for slicing is dependent on whether it is the Simple, Advanced and Expert that is being selected. Below this setting is the slice bottom and once a model is sliced, it is saved as G-code format for printing.

Description of 3D Printer Used

After slicing the models with PrusaSlicer 2.7.4, it was saved in the default format which is G-code. This is the code 3D printers understands. The printer as seen in Figure 11 is a single extruder printer, it comes in with a built volume of 220 m, 220 m, by 250 mm. The machine dimension is 440x440x465mm. It comes with the standard nozzle diameter of 4.0 mm and nozzle temperature of 260 °C and Heat bed temperature of 100 °C.The G-code commands in a set of numbers as seen in Figure 12. This is what determines the movement of printer nozzle in the different coordinates (x, y, and z). The Ender 3 Neo 3D printer manufactured by

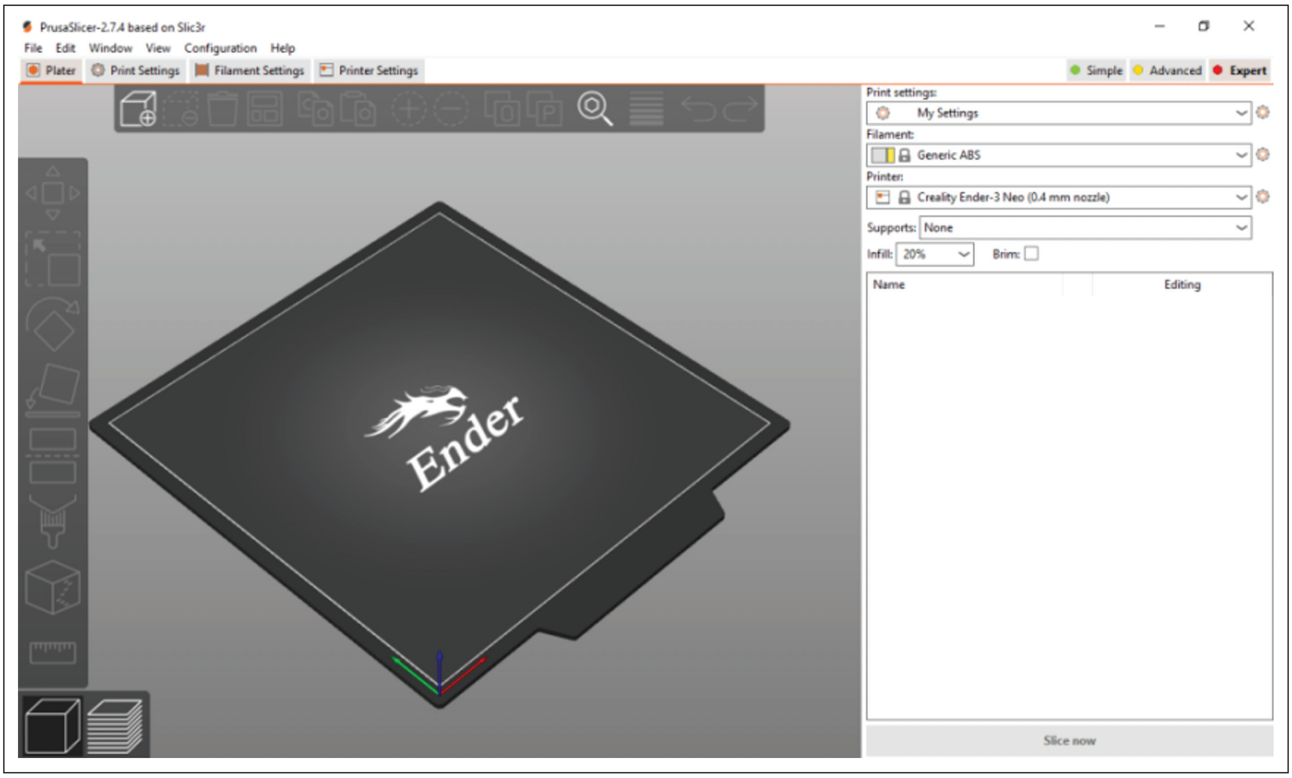

Figure 10. PrusaSlicer software work environment (screenshot by Onosigho, B.O. & Osaigbovo, F.O.).

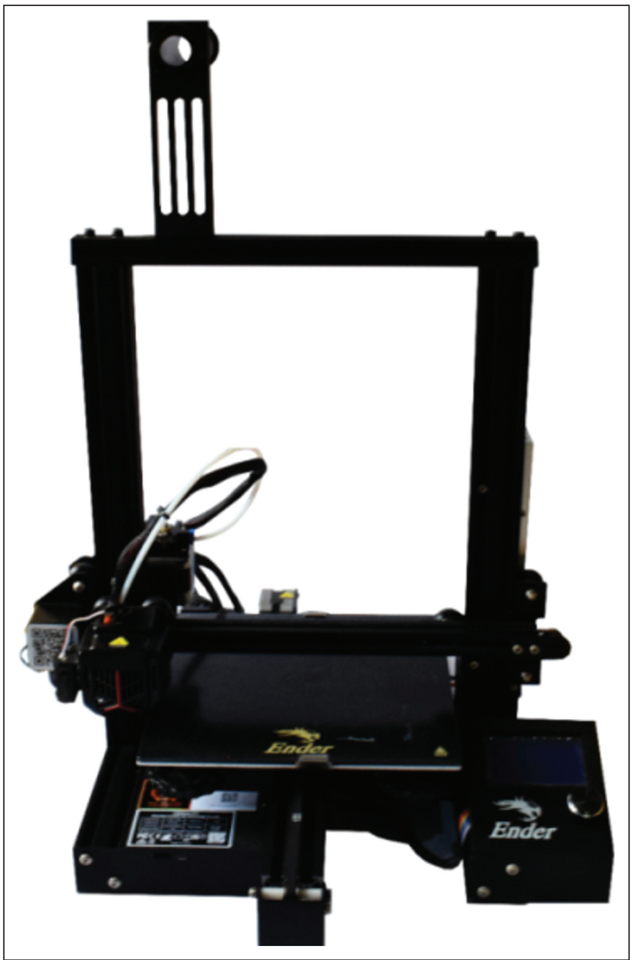

Figure 11. Ender 3 Neo 3D printer dimension: 440x440x465 mm (Photograph: Bennett Onosigho).

Creality, a popular Chinese 3D printing company was used to print the above models.

Some key features of the Printer

- **Open-frame design:** A compact, open-frame structure with sturdy metal base and removable build plate.
- **Average built volume:** A spacious build area of 220x220x250mm (8.66x8.66x9.84 inches) for printing objects.
- **Improved extruder:** A redesigned extruder with tighter filament path and a more reliable hot-end for better print quality.
- **Upgraded electronics:** A Creality-specific motherboard with a silent TMC2208 stepper driver for smoother and quieter operation.
- **Enhanced cooling:** Improved cooling system with a larger heat sink and a more efficient fan for better temperature control.
- **Easy assembly:** A semi-assembled kit with straightforward assembly process, suitable for beginners and hobbyists.

When the G-code is opened with Microsoft notepad, the instructions for each slice are revealed as seen in Figur 12 and this is the path the print head follows layer by layer until the entire object is completely printed.

```
Heart_vase.gcode - Notepad
File  Edit  Format  View  Help

; external perimeters extrusion width = 0.45mm
; perimeters extrusion width = 0.45mm
; infill extrusion width = 0.45mm
; solid infill extrusion width = 0.45mm
; top infill extrusion width = 0.40mm
; support material extrusion width = 0.35mm
; first layer extrusion width = 0.42mm

M201 X500 Y500 Z100 E5000 ; sets maximum accelerations, mm/sec^2
M203 X500 Y500 Z10 E60 ; sets maximum feedrates, mm / sec
M204 P500 R1000 T500 ; sets acceleration (P, T) and retract acceleration (R), mm/sec^2
M205 X8.00 Y8.00 Z0.40 E5.00 ; sets the jerk limits, mm/sec
M205 S0 T0 ; sets the minimum extruding and travel feed rate, mm/sec
;TYPE:Custom
G90 ; use absolute coordinates
M83 ; extruder relative mode
M104 S150 ; set temporary nozzle temp to prevent oozing during homing and auto bed leveling
M140 S0 ; set final bed temp
G4 S30 ; allow partial nozzle warmup
G28 ; home all axis
G29 ; auto bed levelling
G1 Z50 F240
G1 X2.0 Y10 F3000
M104 S200 ; set final nozzle temp
M190 S0 ; wait for bed temp to stabilize
M109 S200 ; wait for nozzle temp to stabilize
G1 Z0.28 F240
G92 E0
G1 X2.0 Y140 E10 F1500 ; prime the nozzle
G1 X2.3 Y140 F5000
G92 E0
G1 X2.3 Y10 E10 F1200 ; prime the nozzle
G92 E0
G21 ; set units to millimeters
G90 ; use absolute coordinates
M83 ; use relative distances for extrusion
```

Figure 12. G-code screenshot: Bennett Onosigho (screenshot by Onosigho, B.O. & Osaigbovo, F.O.).

FINDINGS

Based on these exercises, the following were ascertained about 3D printing:

1. 3D printing is mainly for rapid prototyping; it is quick for creating scale models or prototypes for testing.
2. It is good for the production of end-use products such as consumer goods, machine parts or medical devices and not for mass production because of the time it takes to produce an item. From the above exercises, the larger the item, the more time it takes to complete printing a model. The skeleton full model took 8 hours, 20 minutes to complete, while the heart model and the skull took 5 hours 30 minutes and 5 hours, 35 minutes respectively. So, other larger objects could take up to days to print.
3. Steady source of power is needed to have a complete smooth print. Once there is power outage, it interrupts the printing; however, manufacturers are upgrading their machines to resume prints when power is restored. Even at that, a slight shift is observed on the model which creates a kind of deformity on the model.
4. The space where the printing is been executed should be air tight since other sources of air other than the one produced by the printer for cooling the models as printing progresses will result into stringing. Stringing is the spider like web created between points on print model especially where there are no supports.
5. Appropriate setting is the key to good print out-put. Once there is error in the settings in such areas like the speed, retraction, cooling, style of support and temperature, it could result in defective output.
6. Filament breaking in the course of printing is a sign the filament has expired. Unexpired filament will not break in the course of printing.
7. Only one colour can be printed at a time. Where different colours is desired which can only be applied hori-

zontally because of the movement of the nozzle in z axis, it is imputed in the settings. So, when a colour is to be changed, the printer will pause for the other colour of filament to be loaded after which the resume bottom is pressed for the printing to continue. But in a printing that has multiple extruders, filaments are loaded from the onset.

8. The feedback from the various secondary schools these models were sent to for teaching purposes shows that the students understood the various concepts that these models were used better than previously taught without the use of concrete scientific instructional models.

CONCLUSION

This research effort explored the innovative intersection of 3D printing technology and scientific instruction, highlighting its significance in modern pedagogy, its applications across different educational levels and the potential benefits to students and instructors.

The production of scientific instructional models using 3D printing technology according to Tryssen and Meier (2023) represents a paradigm shift in educational practices and a departure from the conventional two-dimensional learning aids to immersive three-dimensional representations. This shift not only facilitates a deeper understanding of scientific structures and processes but also fosters experiential learning, critical thinking, and problem-solving skills amongst students.

In the light of this research development, this research has delved deeper into the potential applications, challenges, and future directions of utilizing 3D printing technology for scientific instruction. Bomorden and Papenbroch (2020) supports the idea of using 3D instructional models by examining case studies, educational initiatives, and emerging trends in science-graphics field and so these researchers sought to improve on the transformative impact of 3D printing on science education and inspire further innovation in pedagogy.

This research effort has shown that teaching Biology in secondary schools better done using concrete scientific instructional models and it is recommended that future research efforts be done by other researchers to surpass the present research.

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