The use of 3D printing of teaching models of medicinal plants as learning tools in teaching botany

O uso da impressão 3D de modelos de ensino de plantas medicinais como ferramentas de aprendizagem na botânica de ensino

David Bruce Miranda
Postgraduate Degree in Environment and its Technologies
Institution: Instituto Federal de Educação, Ciência e Tecnologia do Amazonas - campus Manaus Distrito Industrial
Address: Av. Sete de Setembro, 1975, Centro, Manaus - AM, CEP: 69020-120
E-mail: d.bruce.miranda@gmail.com

Ana Lúcia Soares Machado
Postgraduate Degree in Environment and Its Technologies
Institution: Instituto Federal de Educação, Ciência e Tecnologia do Amazonas - Campus Manaus Distrito Industrial
Address: Av. Sete de Setembro, 1975, Centro, Manaus - AM, CEP: 69020-120
E-mail: ana.machado@ifam.edu.br

Vitor Bremgartner da Frota
Postgraduate Degree in Environment and Its Technologies
Institution: Instituto Federal de Educação, Ciência e Tecnologia do Amazonas - Campus Manaus Distrito Industrial
Address: Av. Sete de Setembro, 1975, Centro, Manaus - AM, CEP: 69020-120
E-mail: vitorbref@ifam.edu.br

ABSTRACT
The ways of teaching and learning have advanced over the years. The use of 3D technologies is constantly growing. This technology can be applied in teaching through didactic models. At the same time as these technological and scientific advances occur, many may leave aside traditional knowledge and its respective importance, especially in the school environment. This work aims to show the 3D printing of teaching models of the main parts of Amazonian medicinal plants to be used as learning tools in teaching botany. Through bibliographical and field research, three well-known plants widely used medicinally in the Amazon region were chosen: Andiroba, Buriti, and Tucumã. Using 3D modeling programs, seeds and fruits, the materials most used in traditional medicine for these plants, were printed. The results focused on printing models depicting the anatomical structure of the species so that their medicinal importance could be highlighted through the structural visualization of their active principles so that their applications could be understood. The conclusion shows that didactic models can awaken interest in learning by enabling a visual and tactile experience of botanical structures that may not be part of students’ lives, making it possible to rescue traditional...
knowledge with its medicinal application, for example, combined with scientific knowledge, regarding the morphology of the structures presented.

**Keywords:** medicinal plants, 3D printing, didactic models, teaching botany, learning tools.

**RESUMO**
As formas de ensinar e aprender avançaram com o passar dos anos. O uso das tecnologias 3D está em constante crescimento. Essa tecnologia pode ser aplicada no ensino por meio de modelos didáticos. Ao mesmo tempo que ocorrem estes avanços tecnológicos e científicos, muitos podem deixar de lado os saberes tradicionais e sua respectiva importância, principalmente no âmbito escolar. Este trabalho tem como objetivo mostrar o uso da impressão 3D de modelos didáticos das partes principais de plantas medicinais amazonenses para serem utilizadas no ensino de botânica como ferramentas de aprendizagem. Através de pesquisas bibliográficas e de campo, foram escolhidas três plantas conhecidas e muito utilizadas medicinalmente na região Amazônica: Andiroba, Buriti e Tucumã. Por meio de programas de modelagem 3D, foram impressos sementes e frutos, que são os materiais mais utilizados na medicina tradicional destas plantas. Os resultados se concentraram na impressão de modelos com a retratação da estrutura anatômica das espécies para que ficassem evidenciadas suas importâncias medicinais a partir da visualização estrutural de seus princípios ativos para que se pudesse compreender suas aplicações. A conclusão mostra que os modelos didáticos podem despertar o interesse na aprendizagem ao possibilitar uma experiência visual e tática de estruturas botânicas que talvez não façam parte da vida dos alunos, tornando possível o resgate do conhecimento tradicional com sua aplicação medicinal, por exemplo, aliado ao conhecimento científico, quanto a morfologia das estruturas apresentadas.

**Palavras-chave:** plantas medicinais, impressão 3D, modelos didáticos, ensino de botânica, ferramentas de aprendizagem.

**1 INTRODUCTION**

Technological advances have made life easier for most people and would be no different in the educational environment. In addition to using the whiteboard (or chalk) and textbooks, the way of teaching can also advance by using dynamics, games, and teaching models, which opens up another range of methods that can be done and applied when using electronic equipment such as cell phones and tablets to carry out practical activities as well as the different
ways of building a teaching model to visualize better themes or concepts proposed in the classroom.

3D printing and its applications are constantly growing, mainly in terms of technological improvements for its most diverse uses, both in industry and for personal use, and the possibility for educational purposes through teaching models. 3D printing technology is an instrument that can make it possible to create educational models in a personalized and adapted way according to the needs of students, which can be worked on for scientific experimentation, illustrate concepts, facilitate the visualization of biological structures as parts of plants and others (Onisaki; Vieira, 2019).

The relationship between living beings has occurred since the beginning of existence, whether between the same species or not; these ecological relationships are essential for maintaining life, the ecosystem, and the functioning of the environment. The interrelationship of human beings, in their diverse societies and cultures throughout history, with plants present in their closest environment or not, becomes intrinsically related to their social, cultural, or economic way of life where knowledge of medicinal, food, artisanal, among others, are part of its history. The study of the origin of this knowledge and its developments and conceptions can thus define ethnobotany, facilitating the understanding of how certain plants were used and how they can be applied today (Almeida et al., 2022).

Traditional knowledge can be used as a teaching resource in teaching Science or Biology, being applied in botany classes, for example, a form of approach that values prior knowledge, and thus substantiating and contextualizing this knowledge that may have been passed between generations (Basso et al., 2021). It is one of the ways of valuing local and regional knowledge that is often suffocated by knowledge from other, more distant places and said to be more critical than others. By significantly approaching knowledge that students previously know, it opens the opportunity to experiment with traditional knowledge they do not know, and it is up to the teacher to determine the best way
to introduce this new knowledge, using, for example, 3D models of plant parts. medicinal products, such as its fruits and seeds, for example.

With technological advances in all aspects of life and daily life, including teaching, the meanings and consequences are brought to light, as well as conversations and debates about the environment and how to preserve it. Knowledge about nature is not just limited to knowing the species of fauna and flora, for example, but also encompasses an ancestral understanding of their importance both for survival in the past and advancing science in the present and future. The popular wisdom often transmitted orally between generations has also proven helpful in treating diseases through medicinal plants. But where is the recognition of widespread knowledge? Is it still possible to pass on this knowledge combined with scientific knowledge through teaching?

This work aims to rescue ethnobotanical knowledge through anatomical models for 3D printing of the main parts of Amazonian medicinal plants to apply the study and teach botany as a learning tool. It also seeks to promote the importance of traditional knowledge and make the same models available free of charge online for teaching purposes.

2 LITERATURE REVIEW

For many years, for reasons often involving high production costs, 3D printing technology was restricted to engineering, advanced research, or manufacturing (Jakus, 2019). Currently, with the availability of affordable 3D printers on the market, this technology has become widely disseminated and used, both for personal and educational use, about both the development of material production disciplines and the incorporation of 3D printing as public resources that prioritize access to education (Moorefield-Lang, 2014; Brown; Burge, 2014).

In recent years, there has been an increase in the number of subjects offered that use 3D printing in schools and universities, as well as the encouragement of the production and modeling of material in 3D editing software (Ford; Minshaw, 2019; Lombard et al., 2023). It is noted that such a tool is
commonly implemented in pedagogical ways, such as producing demonstrative material, teaching modeling, and printing skills, and creating assistance devices. These elements go beyond the limits of creation since the knowledge acquired in the production of 3D material can be applied in teaching science and technology, mathematics, business and industry, economics, society, art, and environmental education (Schelly, 2015; Christensen et al., 2018; Ford; Minshaw, 2019; Hansen et al., 2020).

Students of the current generation have a greater predisposition to technology-based learning, performing better in practical applications than in classes where hearing and vision are the most used senses (Trembach; Deng, 2018). For this reason, more and more proposals for interdisciplinary applications emerge and encourage students to develop ideas and create models and gadgets that not only fulfill their demonstrative role but also capture the information transmitted in the classroom, making tangible what was initially only in the theoretical scope (Lombard et al., 2023, Wagner et al., 2018).

In biological disciplines, due to the nature of the information studied, learning is heavily based on memorization and theoretical aspects that can be considered abstract and that students may find difficult in terms of their respective understanding as they deal with subjects considered outside of their reality, without a fixed base to cling to, which ends up resulting in a hostile and unmotivated attitude towards the discipline (Connell et al., 2016; Rosenzweig; Wigfield, 2016). Student-centered teaching would be ineffective with the traditional materials currently used in the classroom, that is, textbooks and whiteboards, which, added to the teacher-centered teaching model, end up contributing to students' boredom about the subject (Cimer, 2012; Cheon et al., 2016).

When seeking to overcome this problem, the use of 3D models can cover the most diverse topics, acting as tools in anatomy classes when producing models of bones, tissues and organs (Bernhard et al., 2016; Arshad et al., 2018), molecular models, atomic and cellular structures (Augusto et al., 2016; Lombard et al., 2023) and also function as accessibility materials for students with
intellectual, visual and motor disabilities, such as the creation of informative texts in Braille (Kostakis et al., 2015), pictorial books (Dalton; Musetti, 2018) and geoscience topographic maps (Horowitz; Schultz, 2014), among others.

Botany teaching faces problems related to students' interest in topics related to plants and vegetables, who do not find static living beings as attractive as another form of life, for example, or due to the difficulty that some teachers have in approaching the topic in a way that captures students' attention, treating the case superficially (Ursi et al., 2018). In this way, it is necessary to understand the processes of knowledge construction, which allows reevaluating didactic planning to reduce flaws in the pedagogical approach and allows teachers to find alternative and facilitating ways for creative learning, especially in science teaching. (Krasilchik, 2016).

Melo and collaborators (2012) justify the discomfort in teaching botany with the lack of structure for carrying out practical classes, such as the lack of logistical and financial support for carrying out field classes, the lack of teaching material, and an absent laboratory environment or poorly structured and the difficulty in obtaining materials for each category. Therefore, it is necessary to present alternative ways of teaching botany combined with new technologies that encourage student protagonism in practical classes, making them protagonists of the teaching/learning process (Ursi et al., 2018).

Based on Ausubel's theory (2003), learning must make sense to students, establishing a correlation between prior knowledge and the knowledge to be transmitted in the class. In this way, botany teaching should not only be based on theory or observation but also on everyday life, values, and traditional plant knowledge that permeate the students' routine.

By combining familiar local knowledge in botany classes, students are motivated to share experiences related to the use of plants in their daily lives and, as an alternative way of overcoming problems related to knowledge gaps in botany teaching, the approach of medicinal plants can be an essential tool that enables the interaction between popular and scientific knowledge in interdisciplinary approaches (Silva; Santos, 2017). For Basso et al. (2021), an
appreciation of traditional knowledge is created to preserve it, which opens up space for teaching about it in everyday school life for the authors among young people, a powerful bond with the present, not connecting with the past or perspectives of the future and with the ethnosciencia approach in schools, the connection with the roots of the past can be restored and can create views for the future.

3 RESEARCH METHODOLOGY

The present work is based on bibliographical research and uses the concepts of scientific-technological methodologies developed by Nascimento-e-Silva (2021a; 2021b; 2021c; 2023) to substantiate the answer to the problem presented. In turn, the research approach has a descriptive qualitative character to propose as a means of active methodology the use of didactic models in 3D printing of anatomical parts of medicinal plants found and used in the Amazon to facilitate teaching and learning, rescuing the traditional ethnobotanical knowledge of this region, highlighting it for students and also facilitating visualization as well as promoting the inclusion of people/students with disabilities (PWD) through accessibility when using the printed models created.

To carry out research regarding the concepts and theoretical foundations of the article presented, the Google Scholar website database was used using keywords such as “3D Printing”, “Teaching Material,” and “Ethnobotany,” among others. Regarding the research of selected plants and their medicinal properties, the terms “Astrocaryum aculeatum” and “Medicinal Properties” were searched in Portuguese and English. Other databases emphasizing botany, such as the website Flora e Funga do Brasil (2016), were also used to learn about their scientific names, main characteristics, and images of the anatomical parts that interest the study.

The study began with theoretical research on 3D printing and how it can be used in the educational environment to facilitate teaching and learning in general and can be applied specifically in the education of botany with the printing of the main parts of plants, enabling thus providing a better visual and tactile
experience for students, including those who are PWDs (People with Disabilities), thus promoting inclusion and access to quality education through these forms of learning and also the importance of bringing the baggage of traditional knowledge regarding of medicinal plants that the students themselves can have and can also be presented to them.

The selection of medicinal plants to work on in this article and to print their main parts used in traditional medicine in the Amazon are found and researched in the Permanent Preservation Area (APP) around the Instituto Federal do Amazonas - Campus Manaus Distrito Industrial (IFAM - CMDI). The species were chosen through visits and access to the Saimiri Trail, located in the APP, considering the quantity found, the possible popularity, and confirmation of the species through self-identification using morphological information of the plant, botanical databases and from the published book of the IETÉ Project: environmental monitoring network of the Educandos – Manaus – AM hydrographic basin (2021), which contains the floristic inventory of the area. The medicinal plants chosen were Andiroba (*Carapa guianensis* Abul.), Buriti (*Mauritia flexuosa* L.f.) and Tucumã (*Astrocaryum aculeatum* G. Meyer). Through research into these species, only their anatomical parts, such as leaves, roots, fruits, and seeds, which are most consumed for medicinal purposes found in the literature, will be printed.

Before 3D printing takes place, it is essential to use computer programs. The primary modeling uses the Blender 3.2 program (2002) and the details and finishes in Zbrush (2023). To make printing more accessible and for the pieces to fit together, called slicing, the Meshmixer program was used so that the printing parameters (wall structure, thickness, layers, and speed at which the print will be printed) are as close as possible to the real. After the parts are modeled, sliced, and ready for printing, they are sent to the Slic3r program (2011) for printing to occur on the Ender 3 Creality Printer, located in the Educational Robotics Laboratory (room of the Brazilian Robotics Olympiad, OBR) at IFAM - CMDI.
4 RESULTS AND DISCUSSION

In the Permanent Protection Area (APP), located at the Federal Institute of Amazonas - Campus Manaus Distrito Industrial (IFAM - CMDI), there is a specific diversity of plant species throughout its extension, as stated in the published book of the IETÉ Project (2021). Access to the app through the Saimiri Ecological Trail allows observing these various species. Among them, three with phytomedicinal potential were selected: Andiroba (*Carapa guianensis* Abul.), Buriti (*Mauritia flexuosa* L.f.), Tucumã (*Astrocaryum aculeatum* G. Meyer). After reviewing the literature, it was possible to find the main parts used for medicinal purposes of each plant with their respective photograph that serves as a model for printing the 3D model, which can thus be used in the educational environment, mainly in ethnobotanical themes.

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<td>Seeds</td>
<td>Anti-inflammatory, antiparasitic, fungicidal, and bactericidal</td>
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<td>Buriti (<em>Mauritia flexuosa</em> L.f.)</td>
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Table 1. Medicinal plants, their structures, and importance

Table 1 briefly demonstrates which medicinal plants were chosen for the study, the part of their atomic structure modeled and printed in 3D material, their medicinal importance, and the authors behind the research. These plants can be found in South America but are easily located in the Northern region of Brazil through the Amazon Rainforest. They are used by indigenous people and traditional residents of the area who have a rich ancestral and traditional knowledge of how these plants can be used.
4.1 ANDIROBA

Andiroba or *Carapa guianensis* Abul belongs to the Meliaceae family; the species is predominantly found in Latin America and Africa, south of the Sahara (Ribeiro et al., 2021). Specifically, in Brazil, andiroba is seen more frequently in the North region and Maranhão (Northeast region) throughout a large part of the Amazon Forest; being a native species, it can be found both in “solid ground” forest regions and in floodplains (Flora e Funga do Brasil, 2023).

The medicinal oil extracted from andiroba seeds is classified as a non-timber forest product (NTFP) (Brito et al., 2020). In traditional medicine, andiroba oil has many purposes, among them being an excellent anti-inflammatory, reducing pain associated with arthritis or rheumatism; it also works as an antiparasitic, fungicidal, and bactericidal, in addition, when applied locally in the chest area, it helps the organism in opening the airways as well as reducing respiratory infections (Ribeiro et al., 2021).

The andiroba seed is the central part of the plant from which its essential oil is extracted, used mainly in medicine. Locally, many can be heard about its benefits in people’s lives. Still, few people may have already seen its seed, so using the programs previously mentioned, the andiroba seed was modeled and printed in 3D to facilitate the visualization of where this oil, so crucial to traditional medicine, is extracted.

Figure 1. 3D model - Andiroba fruit (capsule)

Source: Prepared by the authors.
Andiroba fruits are of the globose capsule type, where the seeds are found inside them; when they fall from the tree, they break and scatter. Its roots are generally brown with angled sides of various sizes (Ferraz et al., 2002). According to this information, the construction of this 3D model was modeled in a didactic way so that it is possible to visualize the fruit in the form of a capsule and its seeds (Figures 1 and 2). The printed teaching models (Figure 3) allow students to visualize the arrangement and shape of the source and the capsule that holds them.

4.2 BURITI

Buriti may be one of the best-known palm trees in the northern region of the country; its scientific name is *Mauritia flexuosa* L.f., a species of the Arecaceae family, which has other names such as miriti, marsh palm, and muriti, among others (Carvalho; Santos, 2020). Palm trees (the group in which buriti belongs) have an erect stem, do not have branches, and their leaves are primarily pinnate and terminal; they are generally found in flooded areas and can be found
in different regions of the country, but their largest concentration is in the North (Santos; Araújo, 2022).

The buriti fruit has excellent medicinal potential since knowledge about it and other palm trees is intrinsic to the medicinal knowledge of traditional people around Brazil. However, *Mauritia flexuosa* is in demand for several industries, such as pharmaceuticals, food, and therapy (Ibiapina et al., 2022). It is expected to find pulps for buriti juices or beauty products with it as a base, just as it is possible to see its medicinal/essential oil in local markets. According to the website specializing in Brazilian flora Reflora (2023), the fruit has an oval shape, with the epicarp covered by scales having a reddish-brown color, inside the mesocarp has a yellow-orange color and is a very fleshy region, generally used as food, where its oil can also be extracted for other purposes, such as therapeutic or medicinal.

Buriti pulp, in addition to having a high nutritional level due to the significant presence of fat, fiber, and dietary proteins, has total carotenoids, such as β-carotene, α-carotene, and lutein, which are potent antioxidants and contain vitamin E. The oil extracted from its fruit is mainly used by indigenous people and quilombolas to heal wounds, burns, colds, and antibacterial effects (Carvalho; Santos, 2020).

Figure 4: 3D model - Buriti Fruit

Source: Prepared by the authors.
For 3D modeling (figure 4), the aim was to demonstrate both the external fruit and its interior, molding the texture of the peel to resemble the real thing and, at the same time, showing in another section the internal side with its fleshy endocarp and widely used both for food and medicinal purposes. Its seed is also used in the cosmetic industry to manufacture oils and body lotions. When talking to students about buriti, many likely have already heard about it, and this makes communication more accessible, with prior knowledge and the transmission of traditional wisdom, thus rescuing it using 3D printing. (figure 5), it is a facilitator of learning and visualization of the main parts of the Buriti fruit.

4.3 TUCUMÃ

One of the best-known Amazonian fruits, regionally speaking, tucumã is quite popular, especially regarding food. Its scientific name is *Astrocaryum aculeatum* G. Meyer, also known as tucumã-do-Amazonas or tucumã-açu. It belongs to the same family as buriti, Arecaceae, and is a palm tree with a solitary stem. It can reach 25m in height, and its internodes have thorns of up to 10cm. Found in the terrestrial substrate and Brazil, it is found mainly in the North region, in the states Amazonas, Pará, Rondônia, Acre, and Roraima, and a less concentrated form in Mato Grosso, Central-West [Reflora, 2023].

Tucumã is considered a very versatile fruit regionally. It can be used in regional dishes and snacks, with its oil extracted for therapeutic and medicinal purposes and crafted by hand. Oliveira et al. (2018) report that indigenous tribes use almost 100% of all tucumanzeiro, as do other region residents, using the
stem to make fences and arches the leaves to produce baskets and hats.

The tucumā fruit can also be fully utilized, especially when discussing its pulp and seeds. Besides being extremely nutritious, its pulp has high levels of β-carotene, an antioxidant. Oils and fats can be extracted from its source to manufacture cosmetic products such as moisturizers and body oils. Excellent antioxidants can be found, as well as vitamin B1, which helps in the metabolism of carbohydrates and lipids by acting to obtain energy, and vitamin C, which is essential in healing processes (Corrêa et al., 2022).

When applied to 3D modeling and printing (Figures 6 and 7), the didactic model can offer a cross-section of the fruit its main parts and thus facilitate its visualization; one can observe its peel, which is often used for teas, its pulp, as previously mentioned, is well known in northern cuisine, it is very nutritious with health benefits and last but not least its seed, where its fiber can be used for crafts and have its oil and “butter” extracted to make oils. Essential.
5 FINAL CONSIDERATIONS

Didactic models from 3D printing can act as facilitators, especially in student learning in different ways, by awakening curiosity and having the opportunity to learn about and observe shapes or structures that may or may not be distant from their reality, thus being able to make pieces- keys to the inclusion of students with disabilities, bringing the experience of touching and manipulating teaching materials.

Traditional or ethnobotanical knowledge that may be forgotten over time is recovered when approaching medicinal plants and their main anatomical parts used for this purpose. Three plants popularly known in the North of Brazil were chosen for their medicinal uses and, among other benefits, to disseminate traditional northern knowledge and rescue local expertise for those who live in the region.

Like in Biology, 3D printed teaching models can be applied in different areas of knowledge, such as Chemistry, when printing models of atoms or molecules and even laboratory tools to make knowledge and transmit it more efficiently. In a more didactic and dynamic way by arousing the interest of students and by making it more accessible to those who need it, it is also essential that there are external investments, with public policies that enable the purchase, whether of 3D printers or printing materials, so that it becomes increasingly accessible to schools. Thus, education becomes increasingly valued and of quality for all students.
REFERENCES


