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Development of Chemistry Teaching Materials: Boundless Creativity in Transforming Recycled Materials into Innovative 3D Atomic Models

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Abstract: Chemistry education, particularly in teaching atomic concepts, often faces challenges in visualizing abstract ideas. This study aims to develop three-dimensional atomic models using recycled materials to represent the theories of Dalton, Thomson, Rutherford, and Bohr, while also exploring the potential integration of environmental education within chemistry learning. This research employs an exploratory approach through prototype development, involving six chemistry education students and one instructor. The development process consists of three stages: preparation (literature review and materials collection), prototype development (construction of four atomic models), and evaluation (internal assessment and refinement). The study resulted in four distinct three-dimensional atomic models: Dalton's model uses a 15 cm black plastic ball, Thomson's model incorporates a blue ball with red electrons, Rutherford's model features a wire system with 17 electron caps, and Bohr's model combines styrofoam and aluminum wire to visualize layered orbitals. Analysis indicates that recycled materials can be effectively utilized to create both informative and aesthetically appealing teaching media, while also supporting sustainability principles in education. The main challenge lies in balancing representational accuracy with material limitations, yet this can be addressed through creative material selection and processing. This study contributes to the development of affordable and eco-friendly chemistry learning media, promoting the integration of sustainability values in science education.

Keywords: Bohr's atomic model, chemistry teaching materials, Dalton's atomic model, prototype development, recycled materials, Rutherford's atomic model, sustainable materials, Thomson's atomic model, three-dimensional atomic model.

Introduction

Understanding atomic concepts is a fundamental aspect of chemistry education, yet its abstract nature often poses a significant challenge for students. Three-dimensional visualization of atomic models can bridge the gap between abstract concepts and concrete understanding (Al-Balushi & Al-Hajri, 2014; Derman et al., 2019; Fatemah et al., 2020; Ferk et al., 2003; Marfu'ah et al., 2022; Marfu'ah & Anwar, 2018; Mohamed-Salah & Alain, 2016; Teplá et al., 2022; Trindade et al., 2005), particularly within the historical context of atomic theory development from Dalton to Bohr. In an era where environmental awareness and sustainability are global priorities, developing educational media from recycled materials not only offers an economical solution but also aligns with the zero-waste movement in education (Ebrahimi, 2015; Hannon et al., 2019; Jones, 2014; Pietzsch et al., 2017; Tripathi et al., 2024).

The evolution of atomic theory has progressed significantly, from Dalton's simple model to Bohr's more complex structure (Bailey & Bailey, 2022; Bilir et al., 2018; Bohr, 1934; Dampier & Dampier, 2013; Flowers et al., 2019; Friedrich & Friedrich, 2006; Kedrov, 1949; Khalil, 2017; Kragh, 2021; Niaz & Coştu, 2009; Niaz & Niaz, 2016; Perez, 2024; Rodríguez & Niaz, 2002; Sobel'Man, 2016; Williamson, 1869). Each model has contributed significantly to the understanding of matter's structure, yet its representation in education often remains limited to two-dimensional images in

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textbooks. This may restrict students' spatial comprehension of atomic structure and components. Utilizing three-dimensional models can enhance students' conceptual and spatial understanding (Bain et al., 2020; Cooper, 2020; Fatemah et al., 2020; Garofalo & Farenga, 2021; Harefa & Gulo, 2024; Hew & Cheung, 2010; Huk, 2006; Šafhalter et al., 2020; Teplá et al., 2022), as supported by various studies in science education.

Innovation in the development of teaching media, specifically three-dimensional atomic models, has become a focal point of various studies in chemistry education. However, most existing models use relatively expensive and non-environmentally friendly commercial materials. Meanwhile, Indonesia faces serious waste management challenges, producing up to 175,000 tons of waste daily. Leveraging recycled materials in educational media production could offer a solution that combines educational aspects with environmental awareness (Kioupi & Voulvoulis, 2019; Kurniawan et al., 2023; Menon & Suresh, 2020; Ng et al., 2024; Nourredine et al., 2023; Uda & Basrowi, 2024).

Creativity in developing educational media does not necessarily depend on expensive materials or advanced technology. Simple materials such as used balls, leftover styrofoam, bottle caps, cardboard, and recycled wire can be transformed into effective learning models through innovative approaches. Using recycled materials not only reduces production costs but also provides students with a concrete example of sustainability principles and circular economy practices (Bigdeloo et al., 2021; Bugallo-Rodríguez & Vega-Marcote, 2020; Chen et al., 2020; Garusinghe et al., 2023; Moghayedi et al., 2024; Rahla et al., 2021; Schützenhofer et al., 2022; Spreafico & Landi, 2022; Sukiennik et al., 2021).

This study aims to develop a series of three-dimensional atomic models from recycled materials, including models of Dalton, Thomson, Rutherford, and Bohr. The primary focus is to explore the potential of recycled materials in creating informative and aesthetically pleasing teaching media while documenting the creative process and challenges encountered. This approach aligns with the principles of Education for Sustainable Development (ESD) promoted by UNESCO. The significance of this research lies in the integration of three essential aspects: innovation in chemistry teaching media, environmental education, and economic efficiency. The findings are expected to offer practical contributions to the development of affordable and eco-friendly chemistry teaching media, as well as to inspire other educators to adopt similar approaches.

Materials and Methods

Study area

This study was conducted at a university in South Sumatra, involving a team of six students and one supervising lecturer from the Chemistry Education Program. The methodology employed an exploratory approach (Armstrong, 1970) through the development of atomic model prototypes, without empirical testing of student comprehension. Prototype development was carried out from February to May 2024, focusing on the exploration and creation of atomic model prototypes.

Procedures

This study employs an exploratory approach in the development of atomic model prototypes, consisting of several stages. First, during the preparation phase, a literature review was conducted to understand existing atomic models, followed by the collection and selection of recycled materials, and the design of initial prototypes for each model. Next, in the prototype development stage, four atomic models were created: Dalton's Model, which used used balls; Thomson's Model, shaped like a "raisin bread" made from recycled materials; Rutherford's Model, which adopted a planetary structure using wire and repurposed materials; and Bohr's Model, which illustrated orbitals using recycled materials. Finally, in the evaluation and refinement stage, the team conducted internal assessments of the developed prototypes, which then served as the basis for refining the models and documenting the entire process and its outcomes.

Data analysis

Data analysis in this study was conducted using qualitative descriptive methods, covering several important aspects. First, an analysis of the development process for each model was performed to understand the steps taken. Next, an evaluation of the challenges and solutions encountered during the creation process was examined to identify obstacles and the strategies employed. Additionally, documentation of the physical and structural characteristics of each model was carried out to provide a clear overview of the final results. Finally, an analysis of the alignment of the models with the represented atomic theories was deemed essential to assess the validity of each developed prototype.

Results and Discussion

Result

The development of three-dimensional atomic models from recycled materials resulted in four prototypes that represent the evolution of atomic theory. Each model exhibits specific characteristics aligned with its underlying theory. Dalton's atomic model was created using a black ball made from recycled plastic, measuring 15 cm in diameter and featuring a solid surface, which illustrates the concept of the atom as an indivisible solid sphere. The use of black color in this model emphasizes the fundamental nature of Dalton's theory, which views the atom as the smallest indivisible particle. The prototype of Dalton's atomic model is documented in Figure 1.

Figure 1. Dalton's atomic model

Thomson's atomic model, often referred to as the "raisin bread" model, was implemented using a combination of recycled materials, including a blue plastic ball representing the positive mass, and red elements positioned on its surface to symbolize electrons. This model has a diameter of 12 cm and includes five electron points symmetrically distributed across its surface. The contrasting colors of blue and red facilitate the identification of the model's components. The prototype of Thomson's atomic model is documented in Figure 2.

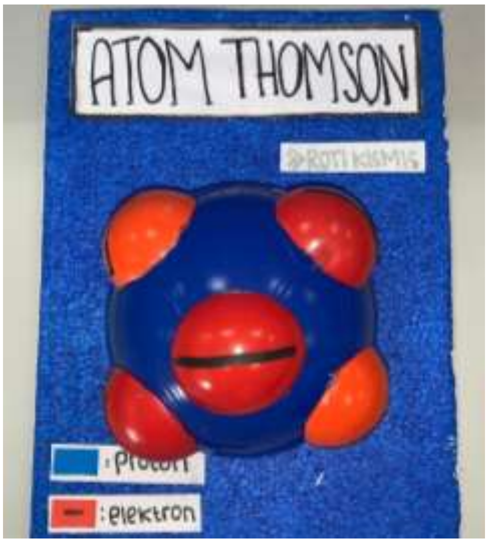

Figure 2. Thomson's atomic model.

In developing Rutherford's atomic model, the research team employed a centered wire system with balls made from recycled bottle caps covered in metallic paper. This model features an atomic nucleus at the center, measuring 3 cm in diameter, surrounded by 18 electrons distributed in circular orbits. The use of metallic materials creates an appealing visual effect and highlights the characteristics of Rutherford's planetary model. The prototype of Rutherford's atomic model is documented in Figure 3.

Figure 3. Rutherford's atomic model.

Bohr's atomic model was developed using a combination of styrofoam and recycled aluminum wire to create a tiered orbital system. This model presents a more complex structure with eight light blue electrons distributed across different energy levels. The atomic nucleus is represented by a green ball with a diameter of 5 cm, positioned at the center of the model. The use of wire for the orbits allows for a clear visualization of the electron energy levels. The prototype of Bohr's atomic model is documented in Figure 4.

Figure 4. Bohr's atomic model

Discussion

Development of three-dimensional atomic models from recycled materials provides a new perspective on sustainable chemistry education. This research yielded several important findings that can be discussed in the context of chemistry education and sustainability. The effectiveness of using recycled materials in the creation of atomic models demonstrates significant potential in addressing the limitations of educational resources. This aligns with the research by Husain et al. (2024), which posited that utilizing recycled materials in educational media not only reduces costs but also enhances the creativity of both educators and students. For instance, the developed Dalton atomic model exemplifies how used plastic balls can be transformed into an effective visual representation of the concept of the atom as an indivisible particle.

Innovation in the use of materials for the Thomson model presents unique challenges in creating an accurate visualization of the "raisin bread" concept. The selection of color combinations and the placement of electrons on the model's surface demonstrate success in visually communicating Thomson's theory. As noted by Blikstein & Wilensky (2009), precise visual representations in atomic models can facilitate students' conceptual understanding of the structure of matter.

The developed Rutherford model provides a clear three-dimensional perspective of the atom as a planetary system. The use of wire and recycled bottle caps in constructing this model illustrates that simple materials can yield sophisticated representations of complex scientific concepts. This finding reinforces the arguments of Lange (2021) and Ncube et al. (2023) regarding the importance of creativity in optimizing local resources for the development of educational media.

The complexity of the developed Bohr model reflects the evolution of understanding regarding atomic structure. The use of styrofoam and recycled aluminum wire to create a tiered orbital system demonstrates that recycled materials can accommodate representations of more complex atomic concepts. This aligns with the research of Kusuma and Hartono (2023), which emphasizes the importance of three-dimensional educational media in facilitating understanding of abstract concepts in chemistry.

The primary challenge in developing these models lies in balancing accuracy of representation with material limitations. However, creativity in the selection and processing of recycled materials allows for the creation of models that are both informative and aesthetically pleasing. As articulated by Hannigan et al. (2022), Ruf et al. (2022) and Wickman et al. (2022), integrating aesthetic aspects into science educational media can enhance student engagement.

The significance of this research also lies in its contribution to education for sustainable development. The use of recycled materials in creating educational media provides a concrete example of implementing circular economy principles in education. This strengthens the arguments regarding the importance of integrating sustainability values into science education practices (Abo-Khalil, 2024; Argento et al., 2020; Brundiers et al., 2021; Caniglia et al., 2021; Gal & Gan, 2020; Hestness et al., 2015; Karaarslan & Teksöz, 2016; Negri et al., 2021; Ralph & Stubbs, 2014; Rico et al., 2021; Tasdemir & Gazo, 2020; Wamsler, 2020; Yarime et al., 2012; Zidny et al., 2020).

Conclusions

The development of three-dimensional atomic models from recycled materials has successfully resulted in four prototypes that represent the evolution of atomic theory from Dalton to Bohr. This research demonstrates that recycled materials can be transformed into effective and aesthetically pleasing educational media through creative and innovative approaches. The success of these model developments not only provides an economical solution for chemistry educational media but also contributes to the integration of sustainability values in science education. Although challenges exist in balancing the accuracy of representation with material limitations, the research findings indicate that this approach is worthy of further development and can be adapted by other educational institutions. This study paves the way for the development of educational media that considers not only pedagogical aspects but also environmental and sustainability concerns.

Conflict of Interest: The authors declare that there are no conflicts of interest concerning the publication of this article.

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