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e-book Multimedia Animation Implementation on Concept Mastery and Problem-Solving Skills of Crystal Structure Subjects in Engineering Materials Course

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ABSTRACT

This study is motivated by students' difficulties in comprehending abstract, complex, and dynamic concepts in the teaching and learning process of the Engineering Materials course. The course is very important because it is indispensable for advanced study program expertise courses. The objective of the study is to evaluate the impact of using the e-book Multimedia Animation (e-MMA) in the teaching and learning process of engineering materials courses on improving students' learning outcomes in the crystal structure subject. The research utilized an experimental method completed with a randomized control group for pretest-posttest design. Two groups were assessed from two classes in Engineering Department randomly selected as the research sample. The subject that becomes the focus of this study is Crystal Structure to understand Concept Mastery and Problem-solving aspects. Thus, there will be two competency data from the research results. The application of e-MMA in the teaching and learning process can improve student learning outcomes. The e-MMA is very effective in solving the problems of students in understanding crystal structure because of their ability to provide images and animations of abstract objects. Students can easily understand the concepts and formulas that exist in the crystal structure concept in engineering materials course.

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1. INTRODUCTION

Currently, technology is rapidly developing and bringing about changes in our daily life, particularly in the field of education. The rapid advancement of science and technology in the field of education has resulted in the modernization of mobile and multimedia technology to produce various teaching models to transform traditional teaching into mobile learning situations (Sun & Pan, 2021; Xie, 2020). Currently, learning tools of higher quality because they are integrated between material and multimedia, such as electronic books (e-books), have emerged to create and provide learning systems that are not limited by space and time by being student-centered and controlled learning situations (Lin & Chen, 2017). According to Leong *et al*. (2019), an e-book is a combination of images, sound, storage media, interfaces, and editing software that helps students in many aspects, including stimulating innovation and thinking skills, exercise aspect, and improving their ability to explore independently. In short, e-books provide more than just text and symbols; they also allow for the inclusion of music, images, and animation (Sun & Pan, 2021). Because the learning designs and learning media are adapted to student development, the impact of this technique is more effective than that of traditional learning media and can further increase students' learning motivation and interest.

Several studies have shown that using e-books can improve student learning outcomes, including: Shamir *et al*. (2018) demonstrated that e-books have a positive impact on improving literacy skills. Hwang *et al*. (2017) discovered that the availability of interactive e-books can facilitate interaction between students and learning content, providing students with numerous opportunities to participate in learning not only in the classroom but also outside of it. Kusumatuty *et al*. (2018) also investigated how e-books can help students with independent learning, investigate students' comprehension of the material to be studied, as well as increase reading and writing skills. e-books as learning resources can help students learn by presenting interesting learning materials. As a result, the selection of appropriate learning resources has an impact on student learning outcomes. It will also have an impact on students' critical thinking skills (Lieung *et al*., 2021). However, in addition to developing interesting learning media and resources, learning media that consider practical and flexible aspects such as the use of e-books should be considered because e-books are very important in learning, particularly in independent learning, because they provide material, methods, and an assessment method that is designed in a systematic and interesting way can help students achieve the expected learning competencies according to their level.

In this study, especially in learning mechanical engineering materials on the topic of engineering materials in the curriculum, students frequently face difficulties in comprehending abstract, complex, and dynamic concepts, which is a problem in the engineering materials learning process. In an engineering materials course, the average percentage of students who can solve problems involving atomic structure, changes in atomic structure, and atomic interactions is 41.6%. In fact, the Engineering Materials course in Mechanical Engineering Education curriculum is a fundamental course that is an important part in the study program expertise courses. This course is offered in the first semester for a total of two credits.

Another issue in the teaching and learning process of engineering materials is that due to the relatively high prices of reference books, particularly original textbooks, not all students have them. Furthermore, there is a language barrier, as most students do not master English in the original text, which indirectly adds to the difficulty of students

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understanding the engineering material course. According to the preliminary findings, students enrolled in engineering materials courses struggle with calculation and abstract atom movement. Efforts are required to solve the problem faced by students, based on the problems and importance of the courses. One of the technologies that can be employed for this target relates to information and communication technology (ICT). Concerning this matter, in short, students can easily access computers to be used in the learning process. Callister has made a special e-book for engineering materials, but the animation is still limited to several aspects:

(i) crystal structure in the form of unit cells. However, this crystal structure has no concern with the characteristics of each unit cell in determining the mechanical properties of the material;
(ii) plane and direction of the crystal arrangement. However, it is with no consideration for the crystal shear plane that precisely determines whether the material is easy to form or not. Further, it is whether soft or hard;
(iii) interstitial point crystal defects. However, it does not include substitution point crystal defects and other crystal defects. As we know, all crystal defects determine the properties of the material, especially the mechanical properties,
(iv) concept has not added with fully information regarding the phase diagram in the material, while it is one of the most difficult materials for students; and
(v) the use of English as the language of instruction. This is still a realistic obstacle for students, especially for students in the non-English speaking country.

Among the efforts to solve the problems, learning media is needed. It is not only in a theoretical level but also in a practical condition. Economical and accessible media is important, especially when it relates to the capability in consolidating the concept of the atomic crystal structure. Some efforts to address issues for the accessible criteria must be pursued by managing concept in the theoretical model (as typically shown as images) into a realistic model. Thus, it is easy to teach and teachable in multimedia form. Based on the description above, the novelty of the e-book-based Multimedia Animation (e-MMA) research can be carried out, including several aspects:

(i) the material and animation aspects. These aspects contain new materials that have not been previously made. Specifically, it must be address in complementing the existing material, such as crystal structures in the form of unit cells, including its characteristics of each unit cell in determining the mechanical properties of the material;
(ii) the language aspect. The language barriers must be solved. For Indonesian, it must use Indonesian as the language of instruction. Indeed, this can eliminate the language barrier for students in understanding,
(iii) the function aspect. The e-MMA has two functions, including a learning resource and as a learning media. As a learning resource, the e-MMA is expected to get the expectations of students to understand the materials. It must be easy to understand. As a learning media, it must meet the characteristics of the media, especially relating to the accessibility for getting the Engineering materials course.

2. CRYSTAL STRUCTURE THEORETICAL PERSPECTIVES

2.1. Fundamental Concepts

Solid materials can be classified based on the regularity with which atoms or ions are arranged in relation to one another. A crystalline material has atoms that are arranged in a repeating or periodic pattern

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across large atomic distances. This is important since crystallinity affects the characteristics of the material (Fatimah *et al*., 2022; Nandiyanto, 2021a; Nandiyanto *et al*., 2020c; Nandiyanto *et al*., 2020d; Nandiyanto *et al*., 2020e).

It means that a long-range order exists, such that when the atoms solidify, they will form a repetitive 3D pattern, with each atom connected and bonded to its nearest neighbor atoms. Metals, ceramic materials, and polymers can form crystalline structures under normal solidification. Noncrystalline or amorphous materials lack this long-range atomic order. Some of the properties of crystalline solids are determined by the crystal structure in the material, which is the arrangement of atoms, ions, or molecules in space. There are many different crystal structures, all of which have long-range atomic order; these range from relatively simple structures for metals to extremely complex ones, as demonstrated by some ceramic and polymeric materials. Atoms are considered as solid spheres with well-defined sizes when crystalline structures are presented. The atomic hard-sphere model is one of the sphere models representing nearest-neighbor atoms connection. In this case, all of the atoms are the same. In the context of crystal structures, the term of lattice refers to a 3D array relating to atom positions and sphere centers (Pan *et al.*, 2020; Evans *et al.*, 1998; Queheillalt & Wadley, 2005).

2.2. A Unit Cell

A unit cell is a building block of the crystal structure, showing the entire crystal structure and symmetry with atomic positions and principal axes (see **Table 1**). The unit cells are arranged and organized in 3D condition, which accurately explains how the crystal's atoms are arranged overall (Zagorac *et al*., 2019). Lattice constants or lattice parameters are the length, edges of principal axes, and angle between unit cells. Seven-unit cell, which are the lengths of the cell edges (*a*, *b*, and *c*) and the angles between them (*α*, *β*, and *γ*), are utilized to define the geometry of the unit cell as a parallelepiped.

Table 1. 7 types of unit cells are adopted from Kamimura *et al*. (2013).

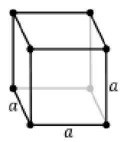
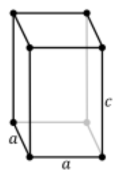
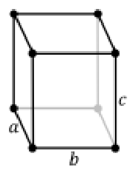
Unit cells	Dimensions and angle	Figure
Cubic	$a = b = c$ $\alpha = \beta = \gamma = 90^\circ$	
Tetragonal	$a = b \neq c$ $\alpha = \beta = \gamma = 90^\circ$	
Orthorhombic	$a \neq b \neq c$ $\alpha = \beta = \gamma = 90^\circ$	

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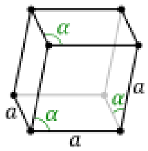
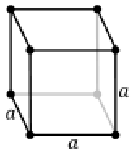
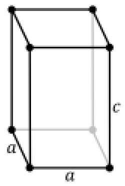
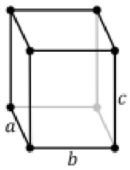
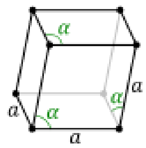
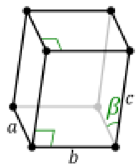
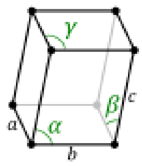
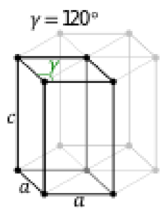
Table 1 (continue). 7 types of unit cells are adopted from Kamimura *et al.* (2013).

Unit cells	Dimensions and angle	Figure
Rhombohedral	$a = b = c$ $\alpha = \beta = \gamma \neq 90^{\circ}$	
Cubic	$a = b = c$ $\alpha = \beta = \gamma = 90^{\circ}$	
Tetragonal	$a = b \neq c$ $\alpha = \beta = \gamma = 90^{\circ}$	
Orthorhombic	$a \neq b \neq c$ $\alpha = \beta = \gamma = 90^{\circ}$	
Rhombohedral	$a = b = c$ $\alpha = \beta = \gamma \neq 90^{\circ}$	
Monoclinic	$a \neq b \neq c$ $\gamma \neq \alpha = \beta = 90^{\circ}$	
Triclinic	$a \neq b \neq c$ $\alpha \neq \beta \neq \gamma \neq 90^{\circ}$	
Hexagonal	$a \neq b \neq c$ $\alpha \neq \beta = 90^{\circ}, \gamma = 120^{\circ}$	

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When measured from a reference point, the fractional coordinates (x_i, y_i, and z_i) along the cell edges describe the positions of spheres inside the unit cell. The coordinates of the smallest possible asymmetric subset of particles must therefore only be reported. This means that not every particle has to be physically located inside the boundaries established by the lattice parameters. Instead, this group of particles may be selected. Thus, it takes up the least amount of physical space (Kestens & Pirgazi, 2016). In more detail, seven types of unit cells are presented in **Table 1**.

2.3. Metallic Crystal Structures

Minimal restrictions as to the number and position of nearest-neighbor atoms are available, leading to relatively large numbers of nearest neighbors and dense atomic packings for most metallic crystal structures. Indeed, when discussing about metals, we employ the hard-sphere model for the crystal structure. Then, each sphere represents an ion core. For most of the common metals, there are three relatively simple crystal structures available: face-centered cubic (known as FCC), body centered cubic (known as BCC), and hexagonal close-packed (known as HCP) (Ono & Ito, 2021; Weinberger *et al*., 2013; Knowles *et al*., 2021).

(i) FCC Crystal Structure. The atoms located at each of the cube faces' corners and centers. **Table 2** shows the examples of metals with FCC crystal structure. **Figure 1** shows the structure for FCC cubic crystal structure.

(ii) BCC Crystal Structure. Another crystal structure is a cubic unit cell with atoms at all eight corners and a single atom in the cube center. **Figure 2(c)** depicts the collection of spheres that describes this crystal structure, whereas **Figures 2(a**) and **2(b)** are the BCC unit cell diagrams with atomic structure represented by the hard-sphere and reduced-sphere models, respectively. Along the diagonals of the cube, the central and corner atoms make contact.

(iii) HCP Crystal Structure. **Figure 3(a)** depicts a reduced-sphere unit cell for this structure; **Figure 3(b)** depicts an assemblage of several HCP unit cells. The top and bottom faces of the unit cell consist of six atoms. They form regular hexagons and surround a single atom in the center. Another plane provides three additional atoms to the unit cell. It is situated between the top and bottom planes. The atoms in this mid-plane have as the nearest neighbors' atoms in both of the adjacent two planes.

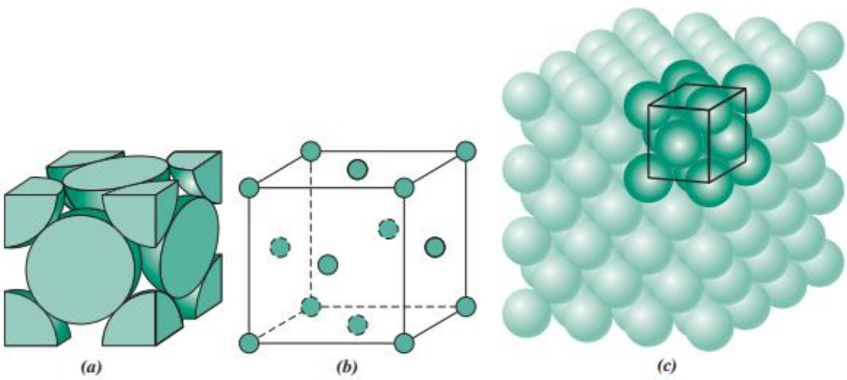

Figure 1. Structure for FCC crystal structure: (a) a hard sphere unit cell, (b) a reduced-sphere unit cell, and (c) an aggregate of many atoms.

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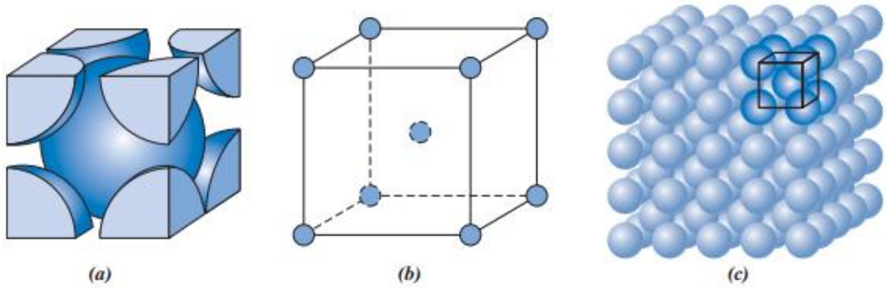

Figure 2. Structure for BCC crystal structure: (a) a hard-sphere unit cell, (b) a reduced sphere unit cell, and (c) an aggregate of many atoms.

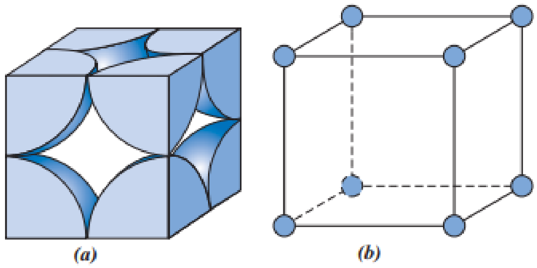

Figure 3. Structure for the simple cubic crystal structure, (a) a hard-sphere unit cell, and (b) a reduced-sphere unit cell.

Table 2. Atomic radii and crystal structure for several metals.

Metal	Crystal Structure	Atomic Radius (nm)
Aluminum	FCC	0.1431
Cadmium	HCP	0.1490
Chromium	BCC	0.1249
Cobalt	HCP	0.1253
Copper	FCC	0.1278
Gold	FCC	0.1442
Iron	BCC	0.1241
Lead	FCC	0.1750
Molybdenum	BCC	0.1363
Nickel	FCC	0.1246
Platinum	FCC	0.1387
Silver	FCC	0.1445
Tantalum	HCP	0.1430
Titanium	HCP	0.1445
Tungsten	BCC	0.1371
Zinc	HCP	0.1332

3. METHODS

3.1. Bibliometric Analysis Method

The method utilized in this study is a bibliometric analysis method with computational mapping analysis. Based on the basic theory of bibliometrics, each analysis uses statistics and mathematics to quantitatively analyze, explain, and visualize the relevant research field. Status and key points can be used for determining and future research trends and hotspots can be estimated. This research was conducted in 5 steps, namely keyword determination, data collection, data processing and analysis, analysis of result and conclusion. The research idea and process of this paper is shown in **Figure 4**.

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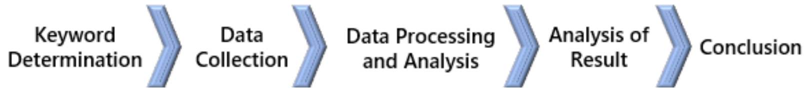

Figure 4. Research ideas and processes.

The keyword used in this research is "Crystal Structure Education". Keywords are set to select articles that are considered relevant. Abstract and Title are used as a reference in selecting articles based on predetermined keywords. The research period used in the review process was carried out from 2012 to 2022. Based on data searches conducted on January 30, 2023 using the Publish or Perish (PoP) application, 1,000 articles were found indexed by Google Scholar. The use of article data indexed by Google Scholar, in which it is a site that provides open-source article search, as well as citations of various kinds of articles without any limitations on the reputation of the article or the publisher of the article.

After data collection is complete, the data is stored in two formats, namely *.ris and *.csv. The *.ris format is used as the format for data mapping in the VOSviewer application, while the *.csv format is used as the format for data analysis in Ms. Excel. Microsoft excel is used to analyze development data every year and sort articles based on the highest number of citations. While VOSviewer is used as an application that can assist in mapping search result data. There are two analyzes performed using VOSviewer, namely Co-authorship and Co-Occurrence analysis. The results of the analysis are in the form of a visualization map. We used two types of visualization, namely network and overlay. Co-Authorship analysis is an analysis of the linkage of articles based on the number of articles written together. The closer the points between authors are, the more these authors write together. Meanwhile, Co-Occurrence analysis is an analysis of the occurrence of a word/term which is visualized in a word presence map. In this analysis the word count method used is the binary method.

3.2. Data Collection Method

This study utilized an experimental method with a randomized control group pretest-posttest design (see **Table 3**). There were two groups from two classes at DPTM FPTK UPI Class of 2013 randomly selected as the research sample. We classified into two classes: Class A (as a Control group), and other is Class B (as an Experimental group). The control group is a class that uses an image as a learning media in the teaching and learning process for engineering materials courses, while the experimental group is a class that uses e-MMA as a learning media in the learning process for engineering materials courses. The subject that is the focus of this research is Crystal Structure with a focus on two skills, the concept mastery and problem-solving. Thus, there will be two competency data from the research results. The stages carried out in the study using the randomized control group pretest-posttest design are as follows:

(i) Pretest. Students from both groups are given a test to determine the concept mastery and problem-solving skills of the Crystal Structure subject material before applying the treatment.

(ii) Treatment. The application of E-MMA for the teaching and learning process in the experimental group, while the control group uses a conventional image as a learning media.

(iii) Posttest. A final test which aims to measure the improvement of student's concept mastery and problem-solving skills after the implementation of e-MMA in the teaching and learning process of crystal structure subject.

To analyze student learning outcomes, the N-Gain test was used, which was based on the pretest and posttest outcomes.

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Table 3. Randomized control group pretest-posttest design.

Group	Pretest	Independent Variable	Posttest
Control	X1		X2
Experiment	Y1	T	Y2

4. RESULTS AND DISCUSSION

4.1. Bibliometric analysis results

Bibliometrics have been used for supporting research analysis in many areas of research (Al Husaeni & Nandiyanto, 2022a; Al Husaeni & Nandiyanto 2022b; Al Husaeni & Nandiyanto 2023; Fatimah *et al.*, 2022; Maryanti *et al.*, 2022; Mubaroq *et al.*, 2020; Nandiyanto, 2021; Nandiyanto & Al Husaeni, 2021a; Nandiyanto & Al Husaeni, 2022a; Nandiyanto & Al Husaeni, 2022b; Nandiyanto *et al*, 2023a; Nandiyanto *et al*, 2021; Nandiyanto *et al*, 2022a; Nandiyanto *et al*, 2020a; Nandiyanto *et al*, 2020b; Nandiyanto *et al*, 2022b; Nandiyanto *et al*, 2023b; Nandiyanto *et al*, 2022b; Nandiyanto *et al*, 2022c; N'diaye *et al*, 2022; Wiendartun *et al*, 2022; Yulifar *et al*, 2021; Nandiyanto *et al*, 2020c; Nandiyanto *et al.*, 2020d; Nandiyanto *et al.*, 2020e).

This study used bibliometric analysis to comprehend the current trend in research regarding Crystal Structure Education.

4.1.1. Development of crystal structure education research

Research on crystal structure education has been published in 100 articles between 2012 and 2022. Titles, abstracts, and article data were filtered for relevance to the research themes identified. The evolution of research on crystal structure education is depicted in **Figure 5**. In general, fewer studies were conducted between 2012 and 2022. There were 161 articles published in 2012, 150 articles in 2013 and 2014, 136 articles in 2015, 111 articles in 2016, 86 articles in 2017, 66 articles in 2018, 67 articles in 2019, 47 articles in 2020, 33 articles in 2021, and 13 articles in 2022.

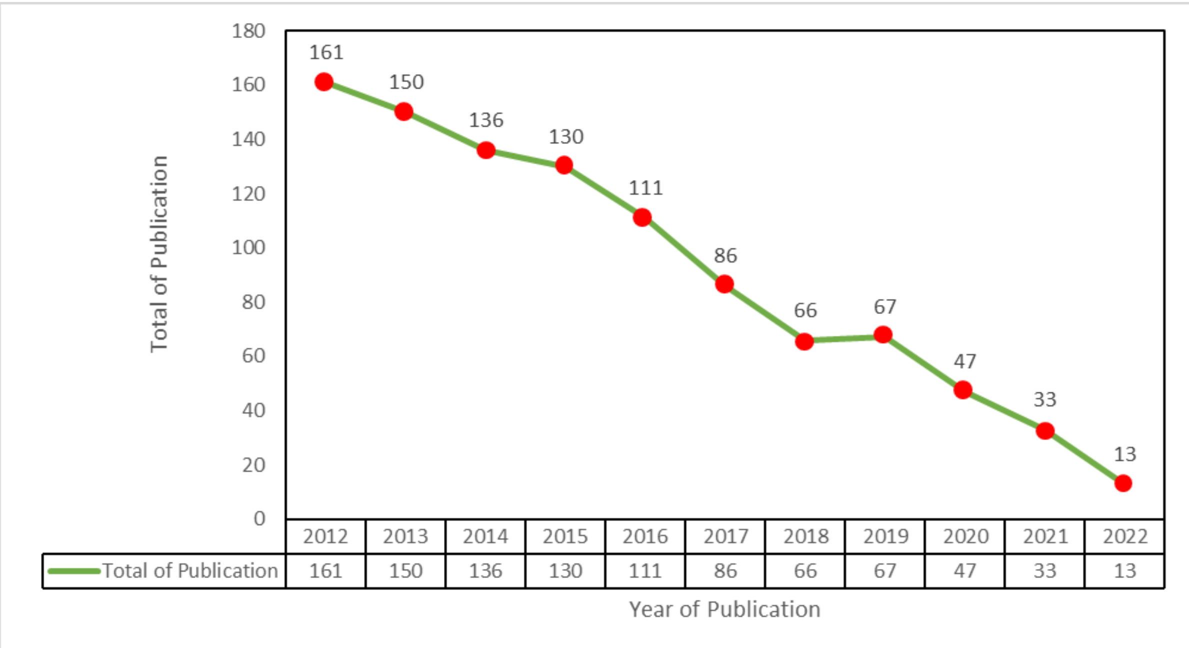

Figure 5. Development of published articles per year related to Crystal Structure Education (2012 – 2022).

4.1.2. The Citations of Crystal Structure Education Article

The research matrix related to the number of citations for crystal structure education research has a total of 137164 research citations out of 1000 articles found and selected in this research analysis. Research on crystal structure education has 137.16 citations per article, with a total of 12469.45 citations per year. The H-index of articles on Crystal Structure Education is 176. The G-Index value of the Crystal Structure Education research in 2012 to 2022 is 294. The detailed matrix of publication data search outcomes are explained in **Table 4**.

Table 5 shows the 10 most cited articles in research on crystal structure education from 2012 to 2022. Articles written by Hanwell *et al.* (2012) rank first with a total of 6392 citations. Research conducted by Hanwell *et al.* (2012) on Avogadro: an advanced semantic chemistry editor, visualization, and analysis for platform. The research was published in the Journal of cheminformatics in 2012. An article entitled "GSAS-II: the genesis of a modern open-source all-purpose crystallography software package" ranks second with the greatest number of citations, with 2929 citations. This article was written by Toby and Von Dreele (2013) and published in the Journal of Applied Crystallography. The 10th place, it is occupied by an article written by Liu *et al.* (2016) in the Journal of the American Chemical Society with a total of 857 citations and entitled "A stable pentagonal bipyramidal Dy (III) single-ion magnet with a record magnetization reversal barrier over 1000 K".

Table 4. Research Matrix on Crystal Structure Education (2012-2022).

No.	Name	Description
1	Papers	1000
2	Citations	137164
3	Cites/Year	12469.45
4	Cites/Paper	137.16
5	Authors/Paper	4.83
6	h-index	176
7	g-index	294

Table 5. The most citations article about Crystal Structure Education (2012-2022).

No	Cites	Title	Year	Ref
1	6392	Avogadro: an advanced semantic chemical editor, visualization, and analysis platform	2012	Hanwell *et al.* (2012)
2	2929	GSAS-II: the genesis of a modern open-source all-purpose crystallography software package	2013	Toby *et al.* (2013)
3	1909	Mercury 4.0: from visualization to analysis, design and prediction	2020	Macrae *et al.* (2020)
4	1771	Review of recent progress in chemical stability of perovskite solar cells	2015	Niu *et al.* (2015)
5	1495	Effect of Nature and Location of Defects on Bandgap Narrowing in Black TiO2 Nanoparticles	2012	Naldoni *et al.* (2012)
6	1300	Synthesis and facet-dependent photoreactivity of BiOCl single-crystalline nanosheets	2012	Jiang *et al.* (2012)
7	890	Affordances of augmented reality in science learning: Suggestions for future research	2013	Cheng *et al.* (2013)
8	875	The Rosetta all-atom energy function for macromolecular modeling and design	2017	Alford *et al.* (2017)
9	863	Record high hole mobility in polymer semiconductors via side-chain engineering	2013	Kang *et al.* (2013)
10	857	A stable pentagonal bipyramidal Dy (III) single-ion magnet with a record magnetization reversal barrier over 1000 K	2016	Liu *et al.* (2016)

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4.1.3. Publisher Analysis

Figure 6 shows publishers who publish articles about crystal structure education. **Figure 6** shows that there are 62 publishers who have published articles on crystal structure education. Elsevier is the most publisher with a total of 230 articles. In second place is ACS Publications with a total of 221 articles. Publisher pubs.rsc.org ranks third with a total of 149 articles. The other publishers sequentially are Wiley Online Library (108 articles), Taylor and FrancAm Soc Microbiol (58 articles), Taylor and Francis (45 articles), Springer (36 articles), iopscience.iop.org (32 articles), ASBMB (22 articles), aip.scitation.org (7 articles) and hindawi.com (6 articles). Other publishers have the same number of articles as academic.oup.com and ashpublications.org have 5 articles. Ccspublishing.org.cn, CSIRO Publishing, dl.acm.org, embopress.org. journals.aai.org, journals.sagepub.com, portlandpress.com, researchgate.net, scirp.org, and scripts.iucr.org has 3 articles. Meanwhile, beilstein-journals.org, cell.com, jove.com, jstage.jst.go.jp, mdpi.com, ncbi.nlm.nih.gov, and pdfs.semanticcholar.org have 2 articles each. Publishers who are not mentioned in the discussion only have 1 article regarding crystal structure education.

4.1.4. Mapping Visualization Analysis

236 related terms were found in the Crystal Structure Education study which had been determined for the number of occurrences to be at least 5 times. We select 100% the most relevant terms.

In data visualization, we create three types of bibliometric visualization maps, namely network, overlay, and density. **Figure 7** shows a visualization of the network of publications regarding Crystal Structure Education in the range of 2012 to 2022. The visualization of the network shows the linkages and the strength of the relationship through the value of the term link strength. Network analysis has the provision that the greater the link strength value, the stronger the relationship between terms.

Each term on the network shown in **Figure 7** is grouped into 7 clusters with different colors. **Table 6** shows the clustering on the mapping analysis regarding Crystal Structure Education.

Figure 8 shows a publication overlay visualization regarding Crystal Structure Education. A visualization overlay depicts a spread of research years to see updates to term usage in related research. **Figure 8** shows that research on Crystal Structure Education is spread the most in the range of 2015 to 2016.

Visualization of the density of Crystal Structure Education research is shown in **Figure 9**. Visualization of color density shows that the brighter the yellow color and the larger the circle size of a term resulted in the more often the term to appear. That is, interest in the term is increasing. The amount of research on the term decreases as the color of the term fades and approaches the background color. In research on Crystal Structure Education the terms crystal structure, synthesis, and structure are several terms with a large number of occurrences.

Figure 10 shows the 10 terms with the highest total number of occurrences. crystal structure has been found 769 times, structure has been found 269 times, synthesis has been found 166 times, property has been found 105 times, study has been found 98 times, crystalline structure has been found 93 times, complex has been found 91 times, education has been found 64 times, xrd was found 54 times, and effect was found 53 times. The term crystal structure is most often found in research data on crystal structure education.

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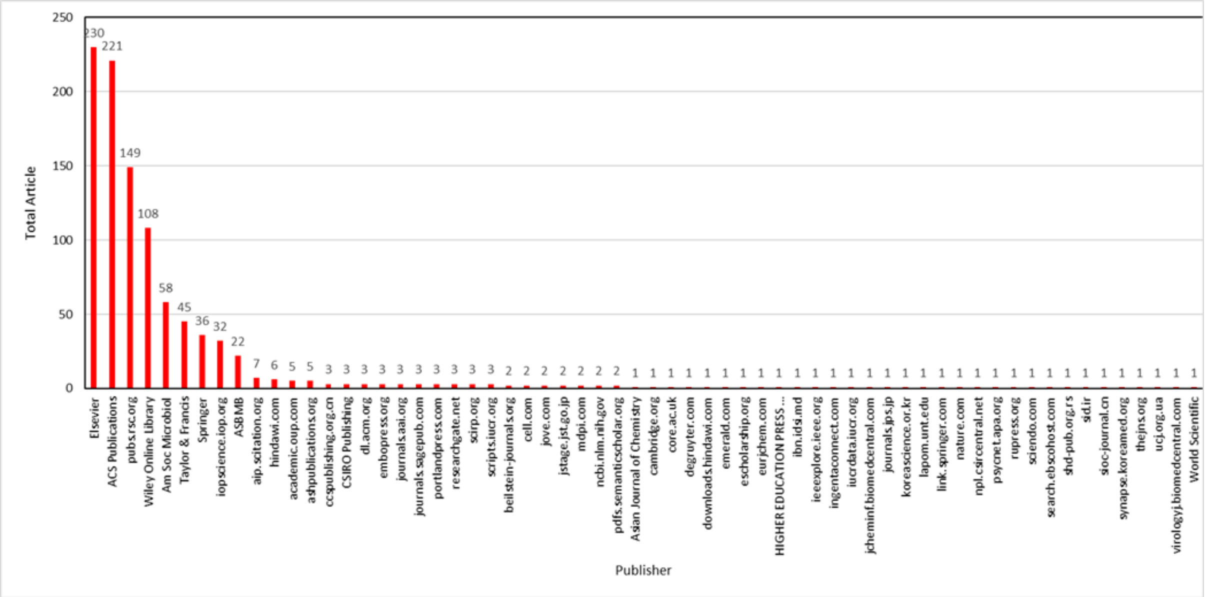

Figure 6. Publishers of Crystal Structure Education Research (2018-2022).

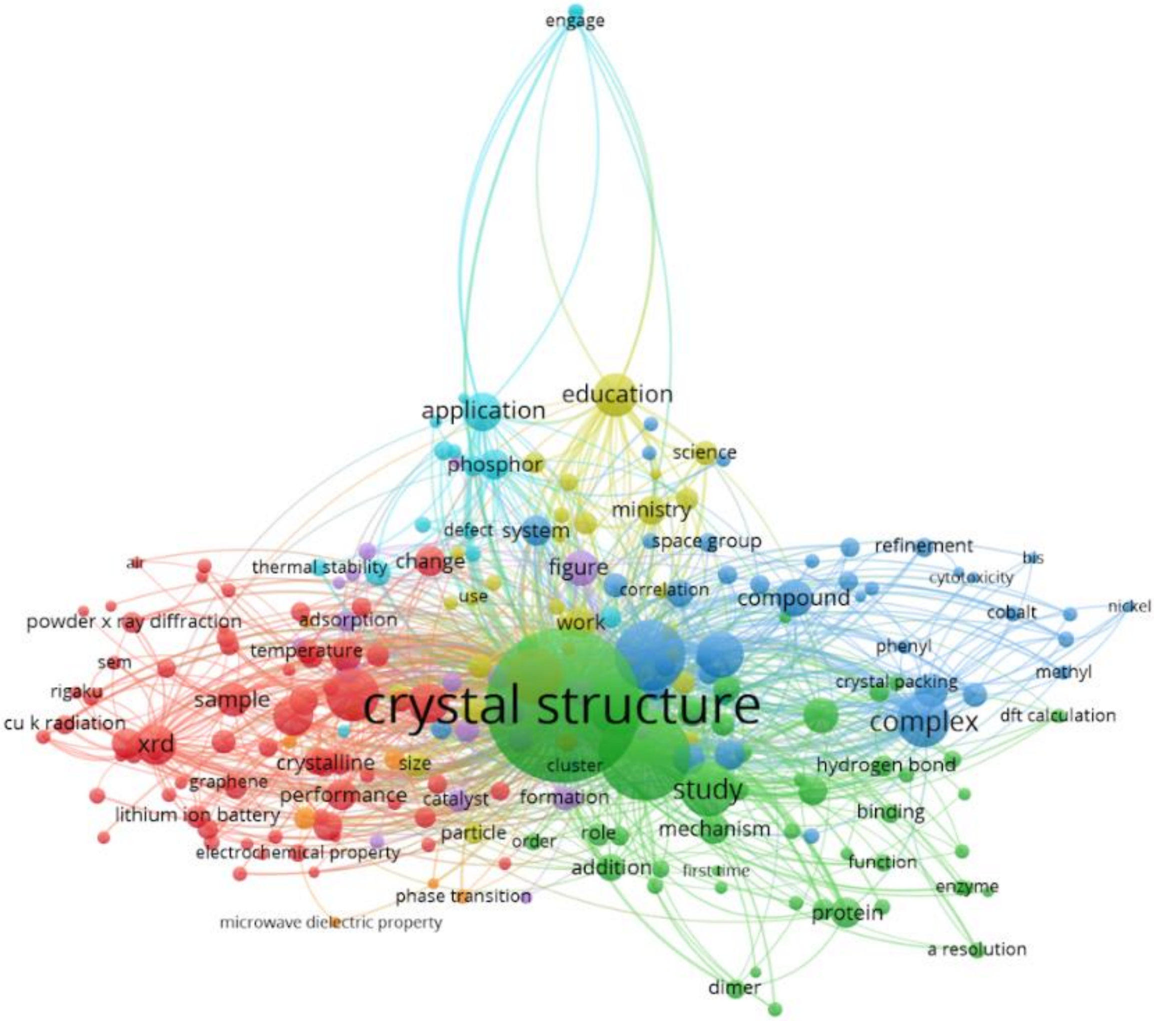

Figure 7. Network Visualization Co-occurrence of Crystal Structure Education (2012-2022).

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Table 6. Cluster Mapping Analysis based on terms.

Cluster	Color	Terms
1	Red	Advance, air, bruker, cathode, cathode material, change, chemical composition, controllable synthesis, crystal size, crystalline, crystalline structure, crystallinity, crystallization, crystallographic structure, Cu K radiation, effect, electrochemical performance, electrochemical property, electron microscopy, enhanced photocatalytic activity, fabrication, facile synthesis, graphene, growth, hydrogen evolution reaction, hydrothermal synthesis, influence, lithium ion battery, microsphere, MnO, modification, mof, nanoparticle, nanosheet, nanowire, nico, optical property, oxide, performance, phase, phase purity, photocatalytic activity, po4, poly, powder, powder X-ray diffraction, precursor, presence, product, PXRD, raman, rigaku, sample, SEM, single crystalline structure, SnO, sodium ion battery, stability, surface morphology, TEM, temperature. thin film, TiO, transmission electron microscopy, X-ray diffraction, XRD, XRD pattern.
2	Green	A resolution, addition, binding, comparison, conformation, crystal, crystal packing, crystal structure, crystal structure determinan, dft calculation, difference, dimer, dimerization, discovery, enzyme, evidence, first time, function, group, high resolution crystal structure, hydrogen bond, information, inhibitor, insight, interaction, interface, mechanism, model, molecular structure, molecule, number, order, present study, protein, residue, resolution, role site, small molecule, structural basis, structural characterization,. structural insight, structure, study, virus serotype, water molecule, X-ray crystal structure.
3	Blue	Aggregation, analysis, antibacterial activity, basis, bis, CCDC, center, characterization, cluster, cobalt, complex. compound, copper, crystal structure analysis, crystallographic data, cytotoxicity, detail, direct method, emission, investigation, ligand, luminescence, luminescent property, methyl, nickel, paper, phenyl, photoluminescence, refinement, Rietveld refinement, room temperature, Schiff base, single crystal, single crystal structure, single crystal X-ray diffraction, solution, space group, structural analysis, synthesis, system, table.
4	Yellow	author, correlation, crystal lattice, crystal structure, development, education, feature, hexagonal crystal structure, higher education, ion, lattice parameter, magnetic properties, magnetic property, ministry, part, particle, range, relationship, research, review, science, size, solid solution, support, understanding, use, work.
5	Purple	adsorption, catalyst, chemistry, CO2, covalent organic framework, crystal data, example, figure, formation, framework, highly, inset, metal organic framework, pattern, reaction, series, step, transformation, type, unit cell, ZIF.
6	Light Blue	application, effect, efficiency, electronic structure, energy transfer, engage, layer, light, luminescence property, phospor, photocatalytic performance, photoluminescence property, physics research, policy, preparation, surface, thermal stability.
7	Orange	ceramic, composition, crystalline phase, microstructure, microwave, microwave dielectric property, novel, phase transition, property, solvent, symmetry.

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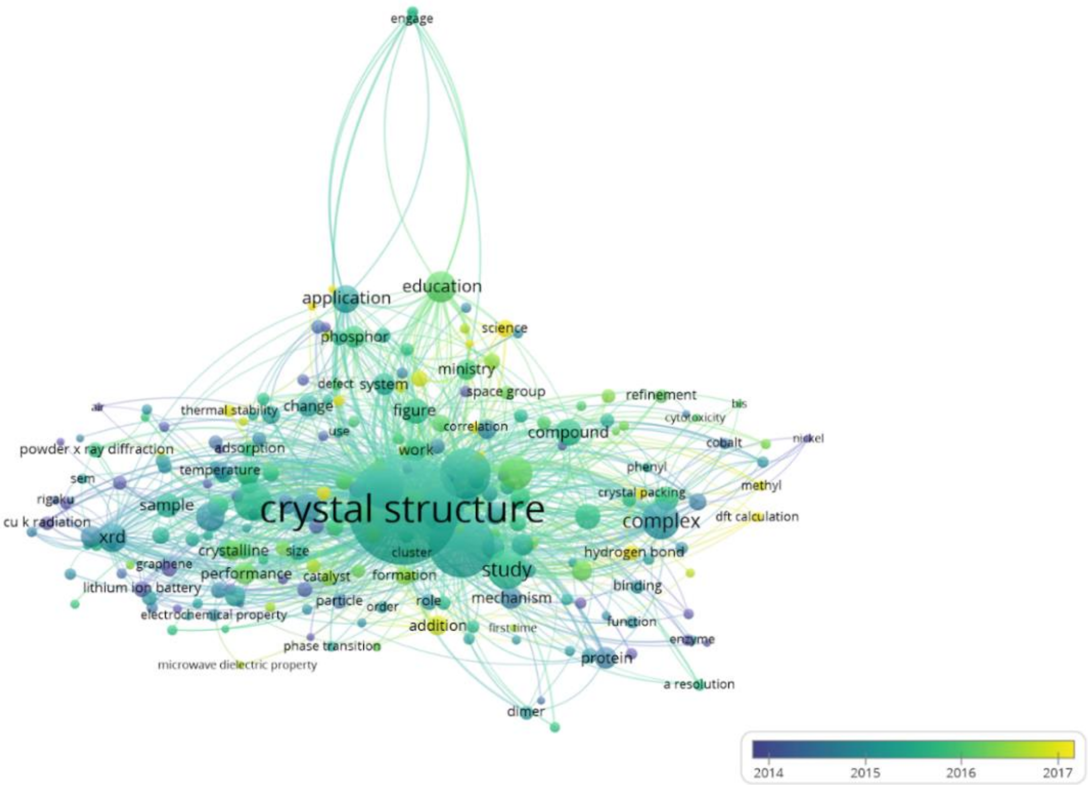

Figure 8. Overlay Visualization Co-occurrence of Crystal Structure Education (2012-2022).

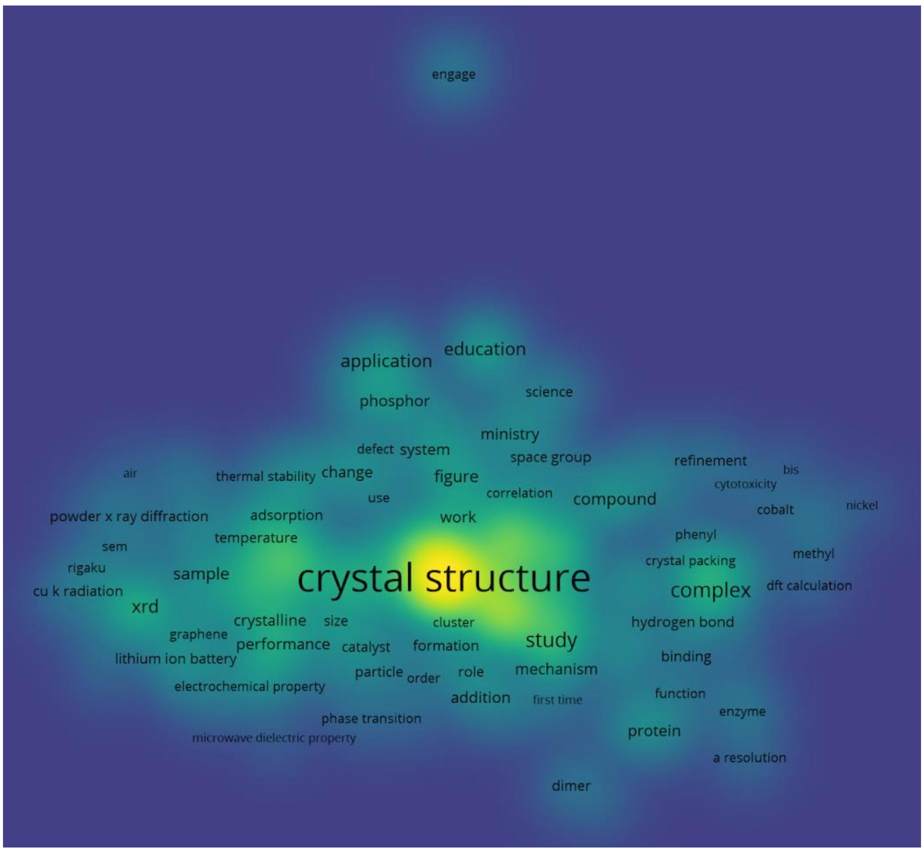

Figure 9. Density Visualization Co-occurrence of Crystal Structure Education (2012 -2022).

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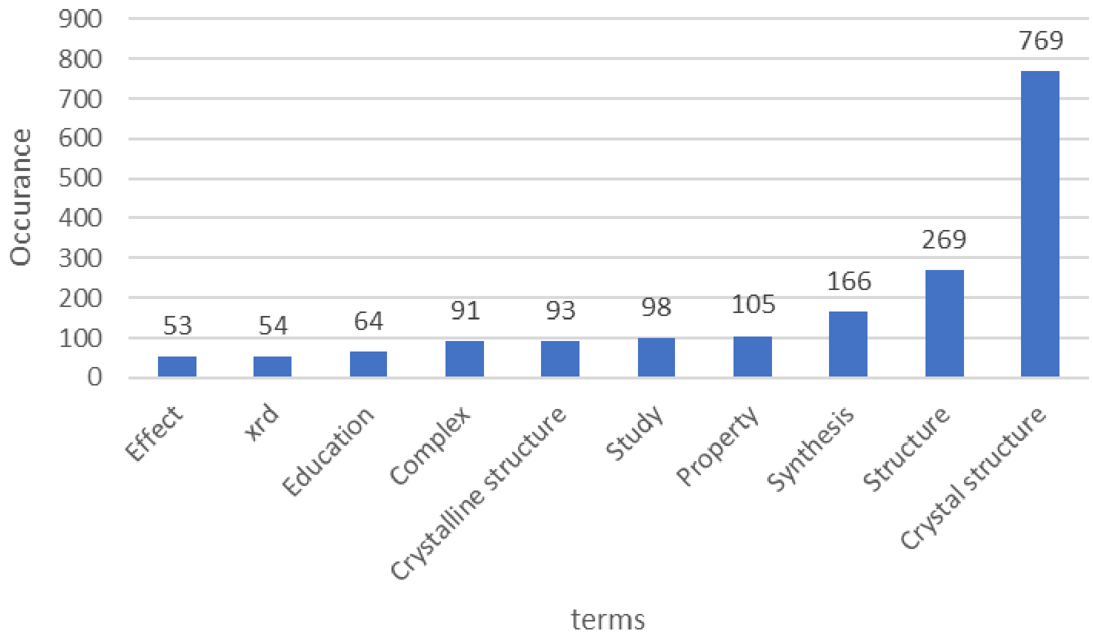

Figure 10. The 10 terms with the greatest number of occurrences.

4.2. Analysis of e-MMA Implementation

The research results were obtained with two focus competencies on the crystal structure subject, the Concept Mastery and Problem-Solving skills. The Pretest and Posttest data are employed to calculate the N-Gain value that is to show an improvement in student learning outcome. The N-Gain values of the control and experimental classes are presented in **Table 7**.

In the calculation results in **Table 7**, the improvement in student learning outcomes on concept mastery of crystal structure subject using e-MMA in the experimental class reached an average of 72.62% or in the high category. This is greater than the improvement in concept mastery using image media in the control class which has an average increase of 29.89% or in the low category.

The improvement of the problem-solving skills of the crystal structure subject using e-MMA in the experimental class reached an average of 87.33% or in the high category. This is also greater than the improvement in problem-solving skills using image media in the control class which has an average increase of 20.44% or in the low category.

The application of e-MMA in engineering materials courses can give improvement in students' concept mastery because it gives more comprehension, bringing better learning outcomes in general. Teaching and learning process using this animation is not only reading but also observing and watching (text, still images, and animated images) and listening. Indeed, it causes the mastery of the material to be increased several times. It is an addition to what students learned, tending it to be remembered longer by students. Learning outcomes from what students learned with animation can be more deeply understood due to its effectiveness in brining long-term memory (Mayer, 2008; Berk, 2009).

The e-MMA in crystal structure material can describe the atomic conditions that are not accessible to the eyes and minds of students to become visible. Thus, it provides a concrete learning experience and is no longer abstract. Realistic images in teaching and learning process can bring a much better impact on the outcomes, referring to the impression that complex concepts can be easily delivered and conveyed with only one image aspect (Nazir *et al.*, 2012). The impact of the learning experiences mentioned is

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proven to increase better concept mastery to high categories. This is in line with the high relationship between media and learning objectives. Media in the form of live-images or animation can give a high relationship to learning concepts. More specifically, the utilization of multimedia animation can improve concept mastery of Engineering Materials course. This is in line with what other researchers do. Falvo (2008) argued that animation of structures and processes can give teachers to convey crucial scientific concepts.

Based on the description and research results, the application of e-MMA can improve concept mastery. This is in accordance with the opinion of Wohl *et al*. (2010). Animation-based education has a major effect on correcting cognitive errors, and animation has been shown to improve student's understanding and learning process.

In problem-solving skills, the improvement that occurred in the crystal structure subject was 87.33% or in the high category. This occurs because the crystal structure material with small atomic size characteristic (not visible) can be depicted well and clearly by e-MMA, and dynamic atomic movements can be visualized clearly by the motion of animated images on e-MMA. This makes it easier to solve the crystal structure problem with e-MMA. The average development in problem-solving skills is increased using e-MMA. It reaches the high category because the animation can improve problem-solving skills in general (Wohl *et al*, 2010). Learning using e-MMA integrates digital technology, where the application of this technology affects the problem-solving process (Holmgren, 2013; Mayer, 1999).

Based on the result and data descriptions, it shows that the application of e-MMA can improve problem-solving skills. Multimedia is proven to be able to improve generic science and solving skills. Anam *et al*. (2009) stated that the utilization of multimedia animation has improved the ability to read projected images, which in this case relates to abstract atomic structure images. In terms of skills and practice, the animation can improve skills and practice as stated by Harsono *et al*. (2009). Thus, this study has the same results regarding improving problem-solving skills through the use of e-MMA. This result is also reinforced by the opinion of Wohl *et al*. (2010). Animation effects the greater desire of students to use strategies to avoid mistakes, which in this case relates to problems that are given to be solved. Another reinforcement was also stated by Holmgren (2013). Learning by integrating digital technology affects the problem-solving process. Thus, in this case, students' problem-solving skills improved. The results of this study are reinforced by the opinion of Mayer (1999). Multimedia learning can promote constructivist learning that allows transferring or producing problem-solving skills.

e-MMA in the atomic crystal structure subject can describe the atomic conditions that are not accessible to the eyes and minds of students to become more real, thus providing a concrete learning experience and no longer abstract. The impact of this learning experience is proven to improve problem-solving skills better to a high category. This success is reinforced by Berk (2009). Multimedia learning provides an empirical basis for use in teaching because it can improve memory, understanding, and deeper learning.

From the results of the data explanation on the improvement of concept mastery and problem-solving skills in crystal structure material, it is proven that learning process using e-MMA can improve concept mastery and problem-solving skills of abstract material in the Engineering Materials course to a high level or category compared to learning process using still-image media.

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Table 7. Pretest, posttest and N-gain result from control and experiment group.

Competencies	Data	Score	Group	
			Control	**Experiment**
Concept Mastery	*Pretest*	Highest	45.00	60.00
		Lowest	5.00	5.00
		Average	25.15	32.44
	Posttest	Highest	85.00	100.00
		Lowest	35.00	45.00
		Average	47.73	81.95
	N-Gain (%)	Average	29.89	72.62
Problem-Solving	*Pretest*	Highest	30.00	55.00
		Lowest	0.00	2.50
		Average	9.29	22.50
	Posttest	Highest	45.00	100.00
		Lowest	12.50	50.00
		Average	28.00	90.18
	N-Gain (%)	Average	20.44	87.33

5. CONCLUSION

The use of e-MMA in the teaching and learning process of engineering materials, especially in crystal structure subjects can improve student learning outcomes with an increase in the high category, both in concept mastery and in problem-solving skills. The e-MMA is very effective in solving the problems of students in understanding crystal structure subjects in engineering materials courses because of their ability to provide images and animations of abstract objects, so students can easily understand concepts and formulas that exist in the crystal structure subject of engineering materials course.

6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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