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Involving STEM Students in Critical Analysis Tasks on the Processes of Modifying Optical Properties of Materials

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The present study reports the use of material modification process in training STEM students' critical analysis skills. The optical properties of the mixed polymer materials (polyvinyl alcohol, methylene blue dye, and trichloroacetic acid) were modified using gamma (γ) radiation techniques. The fabrication process of polymer films blend irradiated with γ rays was carried out by the instructor, including absorbance measurements. The task assigned to the STEM students was to critically analyze the optical characteristics of the irradiated polymer films. The method was divided into two sections: 1) the fabrication of γ-irradiated polymer films, which involved preparation, radiation, and absorbance measurement of the polymer film blend, and 2) the assessment of critical analysis skills in STEM students, which was based on a portfolio of critical analysis tasks. The results of the analysis showed significant changes in the physical properties and optical characteristics of the polymer film blend, including its potential application as γ radiation dosimetry. The results of the critical analysis task of the experimental data indicated that STEM students could complete the task effectively. Overall, the findings demonstrate the effective use of the optical characteristics of polymer films blends irradiated by γ-rays as a tool to facilitate training of STEM students' critical analysis.

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INTRODUCTION

The rapid advancement in technology, particularly in the field of advanced materials modification, is a testament to the progress in STEM (Science, Technology, Engineering, and Mathematics) and is likely to continue as long as individuals in the field remain motivated to discover new and useful applications. The human need for technology is directly linked to the challenges of meeting these needs, as well as the challenges that arise as a result of these advancements. This continuous cycle highlights the importance of individuals in the STEM field possessing strong critical analysis skills in order to effectively address and solve problems (COWAN, 1986; Ra et al., 2019). To foster the development of critical thinking in STEM students, it is crucial to begin this training at an early stage, such as during their schooling, and specifically within their specialized lectures (Wahyudi et al., 2018). The role of instructors in optimizing the course process and fostering critical thinking in STEM students cannot be overstated (Chang et al., 2022).

In the present study, we focus on the development of critical thinking in STEM students, with a specific emphasis on critical analysis, which is often underdeveloped. This is primarily due to traditional teaching methods, which tend to rely heavily on the presentation of reading materials and sources without emphasizing the development of deep-thinking skills in students. Our teaching experience has shown that this approach is not engaging or challenging enough to encourage critical thinking among STEM students.

In the material modification techniques course, we aim to train STEM students' critical analysis skills by inviting them to experiment and analyze the optical characteristics of polymer films blends (polyvinyl alcohol, methylene blue dyes, and trichloroacetic acid) that have been irradiated with γ-rays. γ-Irradiation is a highly advanced material modification technique with a wide range of applications, including radiation dosimetry (Doyan et al., 2021). In recent studies, the modification of radiation film polymers has been focused on analyzing the changes in optical absorption and conductivity of polymers before and after γ-irradiation for potential industrial applications, such as rechargeable batteries (Susilawati et al., 2021).

The research questions of this study are: (1) How do the optical characteristics of polymer films blends (polyvinyl alcohol, methylene blue dyes, and trichloroacetic acid) change when irradiated with γ-rays?; and (2) How do the critical analysis skills of STEM students perform when analyzing the optical characteristics of polymer films blends (polyvinyl alcohol, methylene blue dyes, and trichloroacetic acid) that have been irradiated with γ-rays?

LITERATURE REVIEW

γ-irradiation of Polymer Film Blend

The gamma radiation industry has seen significant growth in various fields such as food processing and preservation, medicine, sterilization of health products, and material modification techniques (Handayani & Permawati, 2017). As a result, research on monitoring the radiation dose of composite materials has been conducted extensively (Gafar et al., 2017). One of the most promising developments in this field is the use of colored thin film polymers as dosimeters for measuring the radiation dose absorbed by materials. This material has several advantages, including portability and low cost (Akhtar et al., 2013, 2016; Kattan et al., 2011).

Film dosimeters have a wide range of applications, including routine low-dose radiation control in food and beverages (El-Kelany & Gafar, 2016), high-dose radiation control in the sterilization of medical devices (Gafar & El-Ahdal, 2014), and radiotherapy (Hassani et al., 2014). In modern industries, dosimeters with dyes are used as an indicator of the dose exposed to the material (Ali Omer & Ali Bashir, 2018; Aydarous et al., 2016; Basfar et al., 2012). Potential polymer-based materials are being developed for their effectiveness at different dose ranges, both at high and low doses (Abdel-Fattah et al., 2014; Soliman et al., 2018; Ticoş et al., 2019). The accuracy and precision of the radiation dose calculation is crucial in these applications (Hosni et al., 2013; Raouafi et al., 2018).

Currently, film dosimeters are mostly developed from polymer-based materials and various dye indicators. Some of the commonly used polymer materials include polyvinyl butyral (Abdel-Fattah et al., 2014), polyvinyl chloride (Kattan & Daher, 2016), polycarbonate (Galante & Campos, 2012), and polyvinyl alcohol (PVA) (El-Kelany & Gafar, 2016; Raouafi et al., 2018). PVA has several advantages over other materials, such as good mechanical properties, water solubility, flexibility, and non-toxicity (Ang et al., 2020; Chaturvedi et al., 2015; Gadhave et al., 2019; Wong et al., 2020). Additionally, various dyes have been mixed with the polymer materials to act as indicators, including cresol red (CR) (Ebraheem et al., 2002), methyl thymol blue (MTB) (Rabaeh et al., 2021), ethyl violet and bromophenol blue (Ebraheem & El-Kelany, 2013), and methylene red (Akhtar et al., 2013). Some studies have also investigated the use of polymer mixtures containing chlorine (Abdel-Fattah et al., 1996, 1997; Doyan et al., 2021; Gafar et al., 2017), which is believed to increase the solubility of dyes in polymer materials and the sensitivity of the dye components in polymer film mixtures.

In this study, we used PVA mixed with methyl blue (MB) and trichloroacetic acid (TCA) dyes. The addition of TCA improves the sensitivity of the dye to the polymer film (Susilawati, 2009) and serves as an electrocatalyst (Dhara et al., 2016). To be applied as a gamma radiation dosimeter, the optical properties of the PVA-MB-TCA polymer film need further exploration. In this experiment, we investigated the characteristics of color change, optical absorption, activation energy, and optical gap energy of γ-ray irradiated PVA-MB-TCA polymer films.

Critical Analysis Skills

In the early 20th century, the term "critical thinking" was popularized by John Dewey as "reflective thinking" (Dewey, 1910). It is commonly identified with the term "reasonable thinking" (Ennis, 2011) or "critical reasoning skills" (Barnet, 1997) and is considered a higher-order cognitive skill (Prayogi et al., 2022). Bloom [40] categorizes cognitive skills into lower-order (knowledge, comprehension, application) and higher-order thinking skills (analysis, synthesis, and evaluation), with critical thinking encompassing the latter three.

Critical thinking is a type of skill that is structured in individual cognitive dimensions (Elder & Paul, 2012). While the standard cognitive dimensions that support critical thinking are much debated, there is agreement that the ultimate goal is to make well-reasoned, analytical decisions (Indrašienė et al., 2021). These cognitive aspects are not hierarchical but rather stand alone and are complementary in nature as intellectual standards for critical thinking.

Critical thinking is a cognitive process that involves in-depth analysis (Fitriani et al., 2019). It is formed based on strong indications of a critical thinker, one of which is analytical skills (Suyatman et al., 2021). As such, critical thinking is also referred to as critical analysis skills. Many experts in the field, such as (Ennis, 2011) and (Facione, 2020), agree that analytical skills are the main standard of critical thinking. This has been supported by a number of studies (Prayogi et al., 2018, 2022; Verawati, Hikmawati, et al., 2020; Verawati, Wahyudi, et al., 2020; Wahyudi et al., 2019) that have employed analytical indicators to measure critical thinking skills.

Analysis is intended to identify actual relationships between statements, questions, concepts, descriptions, or others (Facione, 2020). This includes examining ideas, detecting arguments, and analyzing arguments as analytical sub-skills. Ennis (Ennis, 2015) defines analyzing arguments as identifying conclusions, reasons or premises, simple assumptions, and overcoming irrelevance, looking at the structure of arguments, and summarizing them as a form of analysis. Bloom (Bloom, 1956) developed a taxonomy in the cognitive domain and included elements of analysis as the fourth cognitive level, involving breaking down ideas into several parts and describing the relationships between them.

METHODS

The methodology employed in this study consisted of two main parts: the fabrication of γ-ray irradiated polymer film blends and the assessment of critical analysis skills in STEM students. Figure 1 presents a visual representation of the overall methodology employed in this study.

In the first part, instructors participated in the fabrication process of the γ-ray irradiated polymer film blends, which included the preparation of the polymer film blends, radiation with γ-rays, and the measurement of absorbance. The fabrication process was carried out following established protocols, and the absorbance measurements were performed using standard techniques.

In the second part, the critical analysis skills of STEM students were assessed by tasking them with analyzing the optical characteristics of the γ-ray irradiated polymer films. The students were provided with the necessary information and were asked to identify and analyze the relationships between statements, questions, concepts, and descriptions related to the optical characteristics of the irradiated polymer films. The assessment of critical analysis skills was conducted according to established protocols, such as the Ennis (2015) and Bloom (1956) taxonomies, which include elements such as identifying conclusions, identifying reasons or premises, identifying simple assumptions, identifying and overcoming irrelevance, looking at the structure of arguments, and summarizing them as a form of analysis.

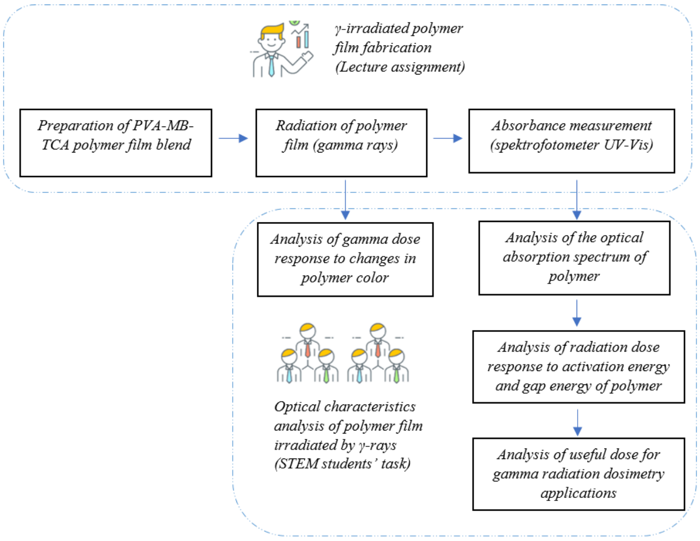

Figure. 1. Overview of study flow.

γ-ray Irradiated Polymer Film Fabrication

Polymer film preparation: Samples of PVA-MB-TCA polymer film blend were prepared using a solvent-casting method. The blend consisted of PVA, MB, trichloroacetic acid (TCA), and color thinners (ethanol and NaOH). The MB dye solution was prepared by mixing 0.08 g of MB (Merck, Germany) with 50 ml of ethanol (96% technical 1L, Merck) and 10% NaOH (M = 0.1M, Merck), and stirring for 15 minutes at room temperature. This solution was then placed in a closed container and left at room temperature. The PVA solution was prepared by dissolving 3.5 g of PVA (Mw = 72,000 g/mol, Sigma-Aldrich, USA) in 100 ml of distilled water, followed by heating and stirring for 5 hours until the remaining volume was 60 ml. 2 g of TCA (Mw = 163.4 g/mol, Sigma-Aldrich) was then added to the PVA mixture, and stirred for 30 minutes. The MB dye solution was then added and stirred for 20 minutes until homogenous. The complete solution (PVA-MB-TCA) was poured evenly on glass plate containers, and left to dry for 120 hours at 25^0C. This formed a solid polymer film with a mixture of PVA-MB-TCA, with a thickness of 0.19×10^{-3} m.

Polymer film irradiation: The PVA-MB-TCA mixed polymer film was irradiated with γ-rays (IRPASENA Irradiator from Cobalt-60 type C-188 source) (BARC, India), with an activity of 80 kCi, and an average energy of 1.25 MeV. The radiation process was carried out at the Research and Development Center for Isotope and Radiation Technology, National Nuclear Energy Agency, Indonesia. A total of 14 samples of polymer films were irradiated successively with radiation doses of 1 to 14 kGy at room temperature. As a comparison, one polymer film sample was not irradiated (0 kGy). It was found that radiation of less than 1 kGy did not change the color of the polymer samples.

Absorbance measurement and analysis: The optical absorption of the PVA-MB-TCA mixed polymer film was measured at all radiation doses using a UV-Vis spectrophotometer (GENESYS 180-type, Genesys, USA) (Double Beam, WL range: 190 - 1100 nm, WL accuracy: ±0.5 nm) in the wavelength range of 300 to 600 nm. The optical absorption characteristics were plotted in the form of a graph of the wavelength vs optical absorption relationship. The activation energy (ΔE) was determined using the Urbach-edges method (Skuja et al., 2004), and the optical energy gap (Eg) was determined using the Mott and Davis model (Mott & Davis, 2012).

Assessment of STEM students' critical analysis skills

In this study, a series of analytical methods were used to evaluate the optical characteristics of a polymer film irradiated with gamma rays. STEM students, who were enrolled in a material modification engineering course at a private university in eastern Indonesia, were involved in the research project. A total of 17 students participated in the project and were tasked with conducting a critical analysis of the optical properties of the polymer material. The assessment of the students' critical analysis skills was based on their report portfolio of assignments. Table 1 provides a summary of the tasks that the students were required to complete.

Table 1. STEM students' critical analysis (CA) tasks.

Tasks	Critical analysis task description
CA tasks-1	• Analysis of the color change on the polymer film as a result of gamma radiation (dose response to the color change of the polymer film).
CA tasks-2	• Analysis of the optical absorption spectrum of mixed polymer films before and after gamma radiation and to analyze the relationship between radiation dose and optical absorption.
CA tasks-3	• Analysis of the magnitude of the optical gap energy for each dose of radiation.
CA tasks-4	• Analysis of useful dose for γ-radiation dosimetry application.

The assessment was based on a report portfolio comprising four assignments given to the students. The data was analyzed descriptively to determine the performance of the students' critical analysis skills.

The score range for each task of critical analysis skills was set between 0 and +4, with 0 being the lowest score for students who did not demonstrate adequate performance and +4 being the highest score for students who demonstrated adequate performance. The scores were calculated for all 17 students and the performance of critical analysis skills was determined based on four critical analysis skills, with the following criteria: poor ($CA \leq 0.80$), less (0.80 < CA ≤ 1.60), sufficient (1.60 < CA ≤ 2.40), good (2.40 < CA ≤ 3.21), and very good (CA > 3.21).

RESULTS AND DISCUSSION

Appropriate analysis results based on observed physical properties and optical absorption measurements using a UV-Vis spectrophotometer are presented and discussed, followed by a discussion on findings related to the performance of critical analysis skills of STEM students.

Color Change in Polymer Films as a Result of γ-Irradiation

The results of the study indicate that the color of the PVA-MB-TCA polymer film samples underwent significant changes as a result of γ-irradiation. Figure 2 illustrates the color change in the polymer samples before and after γ-irradiation, with Figure 2a showing the liquid polymer before drying and Figure 2b, 2c, 2d, and 2e showing the polymer samples after drying and irradiation at doses of 0, 8, 12, and 14 kGy, respectively.

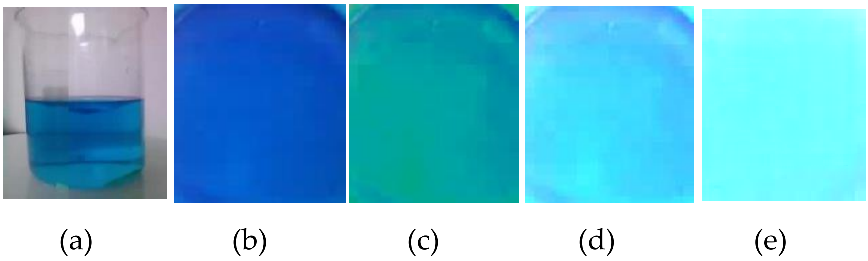
(a) (b) (c) (d) (e)

Figure. 2. PVA-MB-TCA polymer film samples before and after γ-irradiation.

The results of this study indicate that increasing the radiation dose of γ-irradiation caused a significant change in the color of the PVA-MB-TCA polymer film samples. Figure 2 illustrates this phenomenon, with the liquid polymer appearing blue before drying (Figure 2a) and then underwent a gradual shift in color to yellowish blue (8 kGy) and light blue (14 kGy) as the radiation dose increased. The color change is attributed to a decrease in pH (increased acidity) of the polymer film sample as a result of the interaction of TCA with γ-rays, in accordance with previous studies (Doyan et al., 2021). Furthermore, it was observed that PVA polymer film with MB dye (without TCA) did not change color upon irradiation with γ-rays up to 14 kGy. It provided empirical evidence that only TCA molecules in the polymer film samples were affected by γ-irradiation in the specified dose range.

Previous studies have also shown that the intensity of the blue color in the polymer film mixture (PVA-methyl thymol blue) decreases gradually with an increase in the dose of γ radiation, due to the formation of large amounts of free radicals as a result of radiation exposure, which increases the rate of gradual reduction of the blue color in the polymer (Rabaeh et al., 2021). The interaction of γ-rays generates hydrated electrons and free radicals which damage the dye material molecules and remove the chromophore (Aldweri et al., 2017; Rabaeh & Basfar, 2020). As the radiation dose increases, a gradual bleaching of the blue color in the polymer samples is observed (Aldweri et al., 2018). The TCA bonds in the mixed polymer film are dehydrochlorinated, which increases the presence of chlorine ions in the polymer film as a result of γ-irradiation (Susilawati, 2009).

Optical Absorption Spectra of Polymer Films Blend

The optical absorption spectrum of the PVA-MB-TCA polymer film samples were studied using a UV-Vis spectrophotometer. The results obtained from measuring the samples at different radiation doses (0 to 14 kGy) revealed that the maximum absorption occurred at three wavelength peaks: 360, 440, and 560 nm (Figure 3). The first peak is in the ultraviolet region, while the next two peaks wee in the visible region. The trends of the three absorption peaks (360, 440, and 560 nm) were found to be relatively different as a result of γ-irradiation, as depicted in Figure 4. These findings provide insight into how the absorption properties of the polymer film samples change as a result of γ-irradiation.

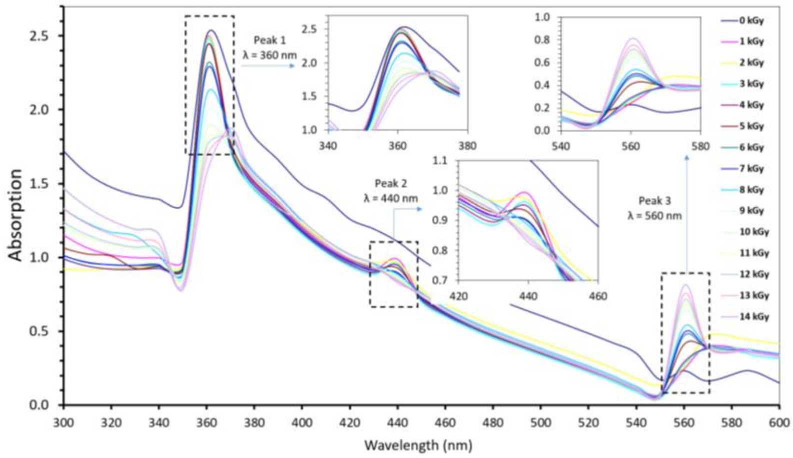

Figure 3. The relationship between wavelength (λ) and optical absorption (A).

The optical absorption spectrum of the PVA-MB-TCA polymer film revealed that the PVA-MB-TCA polymer film samples exhibited maximum absorption at three wavelength peaks, located at 360, 440, and 560 nm (Figure 3). The first peak was located in the UV region, while the second and third were in the visible region. The trends of the three absorption peaks were found to be different as a result of γ-irradiation (Figure 4).

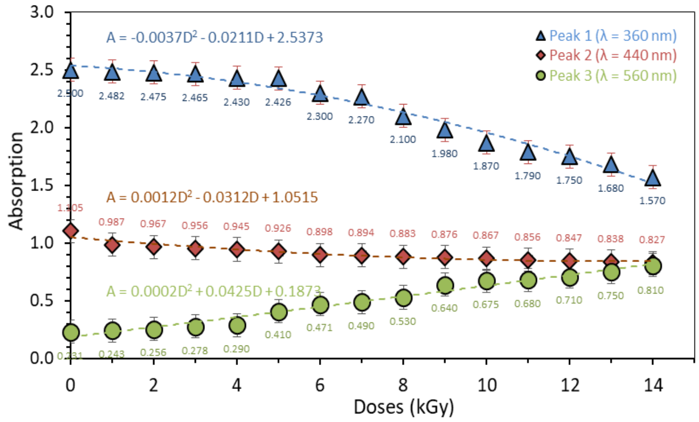

Figure 4. The relationship between radiation dose and optical absorption.

The highest absorption peak was located in the UV region (λ = 360 nm) with a maximum absorption of 2,500 a.u. (0kGy). This absorption value decreased with increasing radiation dose, with a minimum absorption of 1.570 a.u at a dose of 14 kGy. The relationship between absorption and radiation dose was found to be A = -0.0037D2 - 0.0211D + 2.5373. The second peak was located in the visible region (λ = 440 nm), and a trend of decreasing absorption was also observed with increasing radiation dose, but the decrease was not as significant as the first peak. The relationship between absorption and radiation dose was A = 0.0012D2 - 0.0312D + 1.0515. The maximum absorption value at this peak was 1.105 a.u at a dose of 0 kGy and a minimum of 0.827 a.u at a dose of 14 kGy.

In contrast to the first two peaks, the third peak located in the visible region (λ = 560 nm) exhibited a trend of increasing absorption with increasing radiation dose, with the relationship A = 0.0002D2 + 0.0425D + 0.1873. The minimum absorption value at this peak was 0.231 a.u at a dose of 0 kGy and a maximum of 0.810 a.u at a dose of 14 kGy. At the same dose (14 kGy) the maximum absorption value of the third peak was almost the same as the minimum absorption of the second peak, indicating that a balance had occurred between radical formation and consumption in the target reaction (Rabaeh et al., 2021).

The results differ from those of previous studies, which have found that the absorption peaks of organic compounds containing chlorine on the PVA-trichlorethylene (PVA-TCE) polymer film were in the visible region in the 438 and 575 nm bands, respectively (Doyan et al., 2021). At 438 nm the absorption value increased with increasing radiation dose (7 to 12 kGy), while at 575 peak it decreased with increasing radiation dose (0 to 6 kGy), at a concentration of 35% TCE on the polymer film. However, the response of optical absorption to an applied dose of γ radiation was similar between the two studies.

The colorimetric property associated with the dose response of γ-irradiation to changes in the optical absorption peak is an important factor in radiation dosimetry studies (Gafar et al., 2018). Several previous studies have suggested that it is the main criteria for a material to be used as a radiation dosimeter in several applications (El-Kelany & Gafar, 2016; Gafar et al., 2017; Gafar & El-Ahdal, 2014). For dosimetry applications in food, our study identified visible results for PVA-MB-TCA polymer films irradiated at a dose range of 1 to 14 kGy, making it suitable for its application in food processing (Eskin & Robinson, 2001). However, at radiation doses above 14 kGy, the color of the polymer film becomes transparent and cannot be distinguished anymore as the dose increases, thus making it useless for radiation dosimetry applications above this dose range.

In conclusion, the optical absorption spectrum of the PVA-MB-TCA polymer film was studied using a spectrophotometric method. The results showed that the polymer film had three absorption peaks at 360, 440, and 560 nm, with the highest peak in the UV region at 360 nm. The trends of the three absorption peaks were found to be different as a result of γ-irradiation. The first and second peaks decreased with increasing radiation dose, while the third peak increased with increasing radiation dose. These results were different from previous studies on organic compounds containing chlorine on the PVA-trichlorethylene (PVA-TCE) polymer film. The colorimetric property associated with the dose response of γ-irradiation to changes in the optical absorption peak is an important factor in radiation dosimetry studies. Our study identified visible results for PVA-MB-TCA polymer films irradiated at a dose range of 1 to 14 kGy, making it suitable for its application in food processing as a dosimeter. However, at radiation doses above 14 kGy, the polymer film becomes transparent and cannot be distinguished anymore, rendering it useless for dosimetry applications.

Activation Energy and Gap Energy of Polymer Film

The activation energy of a reaction, also known as the minimum energy required to initiate a reaction, was determined using the Urbach-edges method based on UV spectra (Skuja et al., 2004). The method involved drawing a straight line, or exponential function, from the slope of the graph ln (α) to the photon energy (hv) (as shown in Figure 5). The point of intersection between the lines at each hv is the value of the activation energy per radiation dose (as shown in Figure 6). The results indicated that the activation energy of the PVA-MB-TCA mixed polymer film prior to irradiation was 0.305 eV. As the radiation dose increased, the activation energy trended downward, with a linear relationship of ΔE = 0.001D2 - 0.0203D

+ 0.2672 (r = 0.91). The lowest activation energy of 0.165 eV was found at the highest radiation dose of 14 kGy. This finding is consistent with previous studies that have shown that activation energy decreases as the gamma radiation dose increases (Susilawati, 2009). This is attributed to the chain-scission of polymeric molecules within the polymer film (Singh & Neerja, 2007).

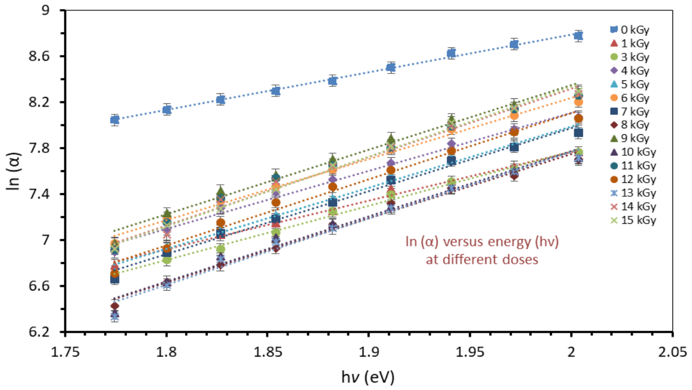

Figure 5. The relationship between hυ (eV) and ln(α).

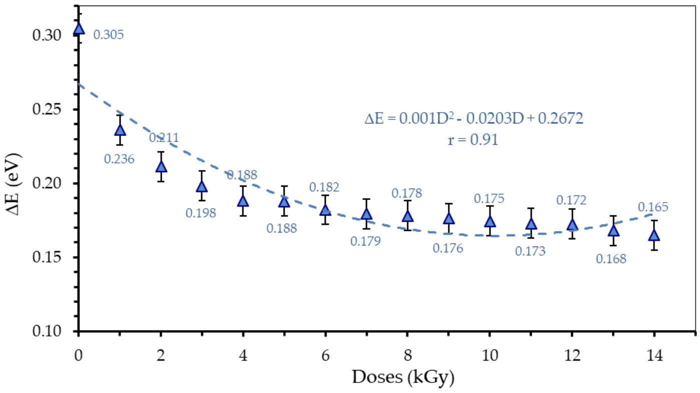

Figure 6. The relationship between activation energy (ΔE) to radiation dose (kGy).

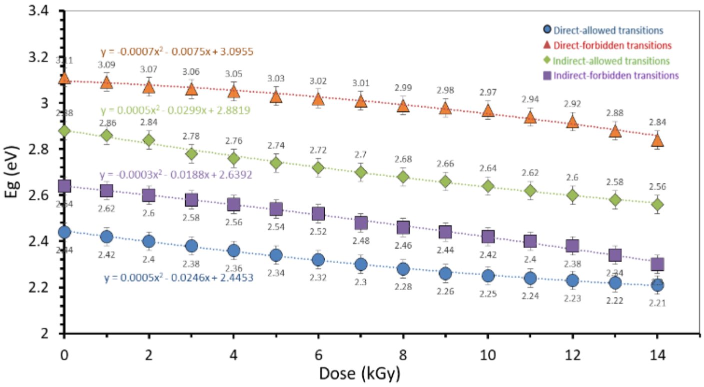

Figure 7. Energy gap (eV) per radiation dose (kGy).

The band gap energy, also known as the energy gap (Eg), is the energy range in a material where no electrons are present, located between the valence and conduction bands (Isac, 2014). In order for electrons to transition between these two bands, a sufficient amount of energy is required (Aziz et al., 2020). The optical energy gap (Eg) was determined using the Mott and Davis model (Mott & Davis, 2012), which involves extrapolating ($\alpha h\upsilon$)m against hv to obtain the gap energy value for each radiation dose. This method generates gap energy values for four optical transitions, namely; $(\alpha h\nu)^{1/2}$ ($m^{-1/2}$ $eV^{1/2}$) for direct-allowed transitions,

$(\alpha hv)^2$ (m^{-2} eV^2) for indirect-allowed transitions, $(\alpha hv)^{3/2}$ ($m^{-3/2}$ $eV^{3/2}$) for direct-forbidden transitions, and $(\alpha hv)^{1/3}$ ($m^{-1/3}$ $eV^{1/3}$) for indirect-forbidden transitions (Escobedo-Morales et al., 2019). These four transitions are shown in the results of this study (Figure 7), where it was found that the band gap energy decreases with increasing radiation dose, across all types of transitions. This decrease in band gap energy is attributed to the increase in polarons and free ions in the polymer samples as a result of exposure to γ-radiation (Aziz et al., 2020; Meftah et al., 2014).

Performance of STEM Students' Critical Analysis Skills

Students' critical analysis skills have been analyzed descriptively. The results are presented in Table 2. The frequency distribution of critical analysis task performance is presented in Table 3.

Table 2. The descriptive analysis results of each critical analysis (CA) task, n = 17.

Parameters	CA task			
	1	2	3	4
Mean (criteria)	3.06 (good)	2.59 (good)	2.41 (good)	2.88 (good)
Std. error of mean	.159	.173	.149	.145
Median	3.00	2.00	2.00	3.00
Mode	3.00	2.00	2.00	3.00
Std. deviation	.658	.712	.618	.601
Variance	.434	.507	.382	.360
Range	2.00	2.00	2.00	2.00
Minimum	2.00	2.00	2.00	2.00
Maximum	4.00	4.00	4.00	4.00

Table 3. Frequency distribution of critical analysis (CA) task performance

CA Criteria	CA task -1		CA task -2		CA task -3		CA task -4	
	f	%	f	%	f	%	f	%
Very good	4	23.53	2	11.76	1	5.88	2	11.76
Good	10	58.82	6	35.29	5	29.41	11	64.71
Sufficient	3	17.65	9	52.94	11	64.71	4	23.53
Less	0	0.00	0	0.00	0	0.00	0	0.00
Poor	0	0.00	0	0.00	0	0.00	0	0.00

The results of this study indicate that STEM students have successfully completed each critical analysis task related to the optical characteristics of polymer films irradiated by γ-rays. The average critical analysis score falls in the "good" category, as shown in Table 2. The highest score was obtained for CA task-1 (3.06), followed by CA task-4 (2.88), CA task-2 (2.59), and CA task-3 (2.41). The frequency distribution of the four critical analysis tasks falls within the criteria of "very good," "good," and "sufficient." None of the students scored in the "poor" or "less" categories, as shown in Table 3. The finding suggests that they possessed a strong ability to conduct critical analysis of the optical characteristics of polymer films exposed to γ-radiation.

In CA task-1, students were able to analyze the color change of the polymer film as a result of γ-radiation exposure. They analyzed the dose response to the color change of the polymer film and developed sound arguments based on their analysis. For example, they compared their findings to previous studies (Rabaeh et al., 2021), which showed that the color intensity of the polymer decreases with an increase in the dose of γ-radiation caused by the formation of large amounts of free radicals due to radiation exposure (Rabaeh et al., 2021). The interaction of γ-rays with the polymer film produced hydrated electrons and free radicals, which damage the dye material molecules and remove the chromophore (Aldweri et al., 2017; Rabaeh & Basfar, 2020). Additionally, the TCA bond on the mixed polymer film was dehydrochlorinated, which increased chlorine ions in the polymer film due to γ-irradiation (Susilawati, 2009).

In CA task-2, students were able to analyze the optical absorption spectrum of mixed polymer films before and after γ-radiation exposure and analyze the relationship between radiation dose and optical absorption. They practiced analyzing each optical absorption peak that was formed and were able to analyze the γ radiation dose, which is useful for dosimetry applications (related to CA task-4). In several reports, students suggested that the colorimetric properties associated with the dose response of γ-irradiation were important factors in radiation dosimetry studies. In CA task-4, students identified results on PVA-MB-TCA polymer films irradiated at a dose range of 1 to 14 kGy as suitable for their application in food processing. As supported by previous studies (Eskin & Robinson, 2001), this range is considered useful for its application as a food processing dosimeter. However, at radiation doses above 14 kGy, the color of the polymer film becomes transparent and can no longer be distinguished, rendering the polymer film useless at higher doses.

Overall, the findings of this study are consistent with the results of previous studies, indicating that literacy in the processing of irradiated polymer materials strengthens the critical thinking abilities of STEM students (Bilad et al., 2022). It is crucial for STEM students to receive intensive critical analysis skills training in order to support their technical skills in the future (Perignat & Katz-Buonincontro, 2018). Furthermore, learning interventions that involve STEM students directly in the process of analyzing the optical characteristics of polymer films irradiated by γ-rays can provide valuable opportunities for students to practice their critical analysis skills.

CONCLUSION

The results of the study revealed that STEM students were successful in conducting critical analysis of the optical characteristics of polymer films irradiated by γ-rays. The average critical analysis score fell in the good category, with the highest score achieved in CA task-1, followed by CA task-4, CA task-2, and CA task-3. The frequency distribution of the four critical analysis tasks fell into the criteria of very good, good, and sufficient, with none of the students achieving scores in the poor and less categories. In CA task-1, STEM students could analyze the color change on the polymer film as a result of γ-radiation and developed strong arguments based on the results of their analysis. They compared their findings with previous studies and explained the mechanisms behind the color change, such as the formation of large amounts of free radicals due to radiation exposure and the removal of chromophores. In CA task-2, STEM students could analyze the optical absorption spectrum of mixed polymer films before and after γ-radiation and analyze the relationship between radiation dose and optical absorption. They practiced analyzing each optical absorption peak that was formed and suggested that the colorimetric properties associated with the dose response of γ-irradiation were important factors in radiation dosimetry studies. In CA task-4, STEM students identified results on PVA-MB-TCA polymer films irradiated at a dose range of 1 to 14 kGy that were suitable for their application in food processing. They supported their findings with previous studies and suggested that the range of 1 to 14 kGy was considered useful for its application as a food processing dosimeter. However, at radiation doses above 14 kGy, the color of the polymer film became transparent and would not be distinguished anymore, making it useless.

RECOMMENDATION

The findings of this study are consistent with the results of previous studies, which suggested that literacy in the processing of irradiated polymer materials could strengthen the critical thinking ways of STEM students. The results of this study indicate that intensive critical analysis skills training is necessary for STEM students to be able to support their technical skills in the future. Furthermore, learning interventions that involve STEM students directly in the process of analyzing the optical characteristics of polymer films irradiated by γ-rays can help them practice their critical analysis skills. These findings have important implications for the education and training of STEM students and highlight the importance of hands-on learning experiences in the classroom.

Author Contributions

The authors have sufficiently contributed to the study, and have read and agreed to the published version of the manuscript.

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Declaration of Interest

The authors declare no conflict of interest.

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