SERD

Comics in modern physics: Learning blackbody radiation through quasi-history of physics

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Abstract

The purpose of this study is to create a short comic story about historical emergence of Planck's explanation of blackbody radiation and to investigate what students learn from it and what they think about the usage of comics in modern physics course. The participants are a small group of undergraduate students studying at department of science education who attend modern physics course in sophomore year. A short comic story about blackbody radiation was created with quasi-historical approach that is defined as re-ordering and re-organizing scientific theories to make sense within historical framework. The comic story was implemented to the participants with a series of open-ended questions. Data were analyzed with qualitative content analysis. Results showed that students have several preconceptions about blackbody radiation before implementation. In addition, it was observed that wrong answers of some students evidently decreased after the implementation of comic story. Moreover, students seemed to enjoy instructional comic story due to its context-based nature, entertaining atmosphere and informal language. On the other hand, students did not report any opinions about the quasi-historical content of the comic story. Therefore, it was concluded that medium characteristics of comics dominate content characteristics of it.

Keywords: Comics, blackbody radiation, history of physics, quasi-history

Introduction

Problem

As a must course for several science and engineering programs at universities, modern physics introduces some remarkable theories developed in 20th century grounding our recent perception of nature and contemporary technology. Concepts of modern physics are accepted as difficult to understand because they are generally related to phenomena having complicated mechanisms that are out of the range of human senses. For instance, unlike classical dynamics

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of macroscopic systems, quantum behaviors of microscopic systems cannot be justified by students' everyday intuitions (Baily & Finkelstein, 2010). As an introductory course, modern physics is expected to concentrate on meaningful learning of complicated modern physics concepts. However, according to McKagan, Perkins and Wieman (2006), modern physics courses are generally taught in a way focusing only on mathematical solutions of abstract problems while ignoring reasoning development, model building and connections to real world applications.

For a better understanding of modern physics concepts, a historical approach may be useful. Because, physical theories of 20th century were developed with regard to some historical conflicts to previous classical theories. Using this approach, students may realize historical context of theories, which may contribute meaningful learning. However, according to Brush (2000), physics textbooks do not sufficiently emphasize historical background of modern physics concepts and some of them distort some historical facts. Similarly, Leite (2002) points out that textbook writers do not give importance to historical development of physics concepts in their textbooks because there is not enough emphasis on history of physics in physics curricula. In addition, Whitaker (1979) states that many physics lecturers unfortunately prefer passing on the discussion about historical development of modern physics theories. This study tries to develop a short historical fiction comic story aiming to contribute conceptual understanding of blackbody radiation without deforming historical facts and to get preliminary feedback about the use of it in instructional process.

Literature Review

A truthful history of physics does not always seem to be appropriate for modern physics courses, because chronological order of historical events does not always fit logical order. For example, Rayleigh's and Planck's equations of blackbody radiation is published in the same year, 1900, showing that Planck's motivation could not be related to contradiction between Rayleigh's equation and experimental results (Whitaker, 1979). Nevertheless, Planck's unawareness of Rayleigh's equation does not change the fact that classical approaches were not successful to explain empirical findings about blackbody radiation. Therefore, it is acceptable to ground modern physics courses on the base of the fall of classical theories at the beginning of 20th century. This problem is generally solved with the quasi-history approach. According to Whitaker (1979), quasi-history is defined as organizing scientific theories in order to make sense where history provides a framework in which they fit easily. As stated above, it is an example of quasi-history to imply that Planck developed his blackbody radiation equation to correct Rayleigh's work. Because, there are no historical evidences about that they were aware with each other before the publication of their papers. On the other hand, quasi-history does not have the same meaning as pseudo-history. According to Allchin (2004), pseudo-history is defined as myths and stories fostering misleading images about historical events by distorting historical facts or using them selectively. Some well-known examples of pseudo-history are apple falling on Newton's head and Archimedes shouting "eureka" while running naked. Pseudo-history is generally disadvantageous in learning science. One of the most important disadvantages of pseudo-history is that it over-simplifies scientific process (Allchin, 2004). Stating that Newton realized gravitation when an apple fell on his head is a clear example of over-simplification of scientific process through ignoring experimental and mathematical works behind a scientific discovery.

Literature gives a useful rationale for using history of science in physics instruction. According to Seroglou and Koumaras (2001), history of physics provides teachers with important knowledge about how a scientific concept has been constructed and evolved which may contribute conceptual change. For instance, comparing the ideas of Aristo and Newton in the classroom may help students to reconsider their preconceptions about moving objects. Likewise, historical development of a scientific concept is a similar process to individual comprehension of it (Galili & Hazan, 2001). In addition, Seroglou and Koumaras (2001) express that history of science may contribute students' understanding of nature of science with its relationships to social, political, cultural and moral issues.

This study uses comics as a medium carrying a quasi-historical fiction story about modern physics. Tatalovic (2009) basically defines comics as sequential art associated with text telling short stories. Similarly, Rota and Izquierdo (2003) describe comics as pictorial illustrations arranged sequentially to transmit various messages. Several advantages of comics are mentioned in the related literature. Firstly, According to Liu (2004), comics increase students' reading comprehension even in high-level text due to the joint effect of verbal and visual coding. In addition to increased reading comprehension, Tatalovic (2009) reports that comics improve enjoyment of reading science because of humorous nature of them. Moreover, according to Cheesman (2006), beginning a science lesson by demonstrating comics transfers the students in a more receptive mood and initiates critical thinking. Similarly, Jee and Anggoro (2012) state that comics have positive effect on science learning because visual models in comics make science concepts more concrete and accessible.

Purpose

The purpose of this study is to produce a short comic story about historical emergence of Planck's explanation of blackbody radiation and to examine what undergraduate students learn from it and what they think about the usage of comics in modern physics course. Briefly, as a learning material for modern physics courses, this study aims to produce and evaluate a short comic story about blackbody radiation.

Methodology

Research Design

Within the qualitative research model, this study is basically a case study in which how participants respond to the implementation of a new learning aid is examined. Specifically, this study qualitatively investigates the case of development and implementation of a quasi-historical comic story about blackbody radiation. In the following sections, characteristics of the participants, development of the comic story, instruments for data collection, implementation of comics, data collection and data analysis are explained in detail.

Participants

Because of the qualitative nature of its purpose and procedures, a case study does not require any random sampling methods. Thus, a convenient group of individuals was selected as participants in this study. The participants are a group of undergraduate students studying at department of science education who attend modern physics course in sophomore year. This group is formed by 37 people in total including 25 female and 12 male students.

Material and Instruments

As mentioned in the previous sections, a short comic story about blackbody radiation was designed and developed by the researcher as a learning material for modern physics course. Briefly, this one-page comic story is a short dialog between a physicist and one of his colleagues who is not a physicist, about Planck's newly published paper about blackbody radiation in 1900. To his confused colleague, physicist tries explaining Planck's controversial theory that demonstrates why a hot body tends not to radiate ultraviolet light in terms of the concept of quantized energy emitted by oscillating charged particles. This comic story focuses only on conceptual understanding of incandescence, thermal radiation and blackbody radiation without discussing underlying mathematical and statistical techniques.

Development procedure of this comic story consists of trials and revisions. Firstly, a draft version of this comic story was created and then reviewed by a group of science education specialists with respect to accuracy, legibility, comprehensibility and quality. A small group of undergraduate students were also asked to read this draft to get feedback. Draft was revised with regard to suggestions from specialists and students in order to develop final version of the comic story for the main implementation. Figure 1 shows final version of the comic story created and implemented in this study. See Appendix A for English translation of text in the comic story.

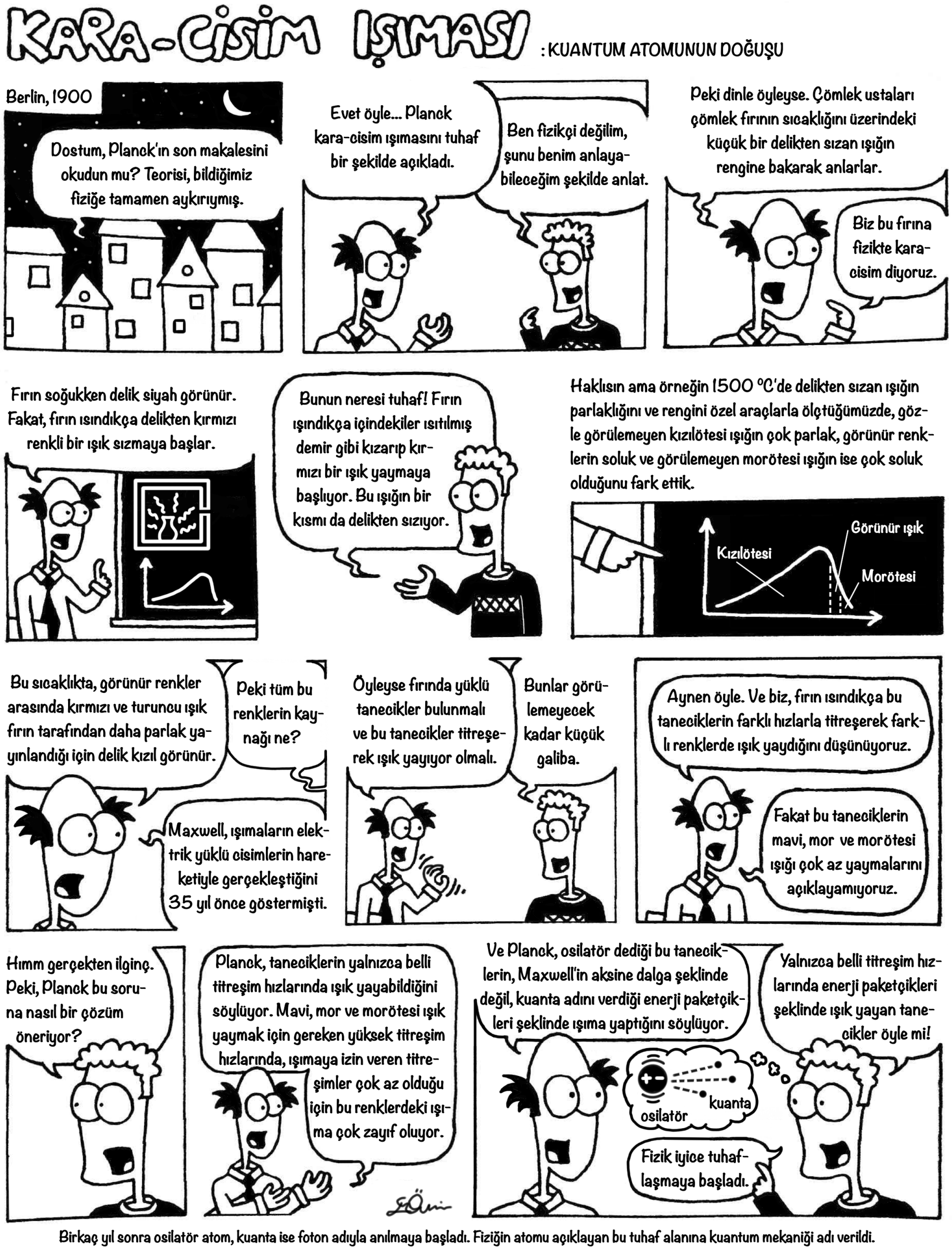

Figure 1. Final version of the comic story created in this study

To collect data on what students have already knew about incandescence and blackbody radiation and what they learned from the comic story, five open-ended questions related to blackbody radiation were asked them. Since blackbody radiation is somehow technical term, it is not included in the stems of these questions. Instead, the terms thermal radiation and incandescence were preferred because of their common daily life usage. These open-ended questions are listed in the Table 1 below.

Table 1. Questions about incandescence and thermal radiation

#	Question
QBR1	Why does lava erupted from a volcano radiate light? Explain.
QBR2	Why do not we observe light when lava gets cold? Explain.
QBR3	With respect to internal structure of matter, what is the source of thermal radiation (e.g. reddish light emitted from an incandescent iron rod, filament of light bulb or hot lava) and how is it emitted? Explain.
QBR4	What determines the visible color of thermal radiation? Explain.
QBR5	What is the structure of light? Explain.

To collect data on students' opinions about the quasi-historical comic story implemented, seven open-ended opinion questions were asked them. These open-ended opinion questions are listed in the Table 2 below.

Table 2. Questions for students' opinions about comics story implemented

#	Question
QSO1	In your opinion, what are the problems of modern physics course?
QSO2	What do you like in the comic story that you just read? Express your positive opinions about scenario, drawings etc.?
QSO3	What do not you like in the comic story that you just read? Express your negative opinions about scenario, drawings etc.?
QSO4	How the integration of quasi-history with comics does contribute learning undergraduate physics concept? What are the benefits of this approach?
QSO5	How the integration of quasi-history with comics does hinder learning undergraduate physics concept? What are the disadvantages of this approach?
QSO6	In your opinion, how can this approach be integrated to modern physics course?
QSO7	In your opinion, how can this approach be improved?

These open-ended questions were asked to participants in written and verbal forms during the implementation. Data from their answers to these questions, which are in qualitative nature, were analyzed to get feedback for further revisions of the comic story.

Implementation

As mentioned above, created comic story was implemented to 37 undergraduate students studying at department of science education who are attending modern physics course in sophomore year. Before the implementation, participants did not perform any learning activities about blackbody radiation within the course. On the other hand, students are expected to have preconceptions about thermal radiation and incandescence based on their previous individual experiences. Thus, the implementation of the comic story was an introductory activity for formal instruction of blackbody radiation. Firstly, open-ended questions about blackbody radiation were asked to the participants at the beginning of the implementation. Then, they were asked to read the comics individually during the same lesson. Then, in the next lesson, open-ended questions about blackbody radiation were re-implemented to the participants. Additionally, in this lesson, opinion form including a series of open-ended opinion questions were applied in order to gather the views of the participants about advantages and disadvantages of the usage of quasi-historical comics in modern physics course. After a quick descriptive analysis of the responses to the opinion form, semi-structured interviews with two selected participants were performed.

Data Analysis

Participants' answers to open-ended question about blackbody radiation and their responses to open-ended opinion questions are freely written texts. Similarly, data from interviews with two participants are formed by verbal responses. In other words, all data collected in this study are in written or verbal form and thus in qualitative nature. Therefore, these data were analyzed via qualitative content analysis that includes coding and categorizing procedures to reveal the meaningful patterns in it.

This study especially focused on participants' wrong answers about blackbody radiation in the first and second implementations. Students' similar wrong and partially wrong answers to open-ended questions about blackbody radiation were categorized into several groups in both implementations. In a similar way, their resembling opinions about the usage of comics in modern physics course were classified into a number of groups.

Results and Discussion

In this section, results of qualitative data analysis of data from open-ended questions about blackbody radiation and from opinion form were separately reported including their interpretations and explanations.

Results from Open-ended Questions about Blackbody Radiation

As stated in the previous sections, participants answered five open-ended questions about blackbody radiation before implementation. Data formed by students' written answers to these questions were analyzed through qualitative content analysis including the process of coding and categorizing similar answers. In general, it was observed that students have several preconceptions about thermal radiation and incandescence before implementation. Summary of the results including coded categories of students' wrong answers with their brief explanations is reported in Table 3.

Table 3. Summary of the results from open-ended questions about blackbody radiation before implementation

Category	Explanation
INCCOMB	Incandescence is a kind of combustion reaction.
COTYPMAT	Color of thermal radiation depends on type of matter.
INCSUN	Structure of incandescent lava is the same as Sun's structure.
BECOPAQ	When an incandescent object gets cold, thermal radiation stops because it becomes an opaque solid.
STOPVIB	Vibrations of particles stop in frozen objects.

As seen in Table 3, students seem to have several preconceptions about thermal radiation and incandescence before the implementation. For instance, some students stated that incandescence is a kind of combustion reaction (INCCOMB). Probably, this preconception is related to apparent similarity between incandescence and combustion in which radiation from both are perceived as hot due to accompanying infrared radiation. In addition, many students expressed that color of thermal radiation depends on type of matter (COTYPMAT). In other words, they believe that different objects formed by different matters glow in different colors when they become incandescent. This belief may be related to flames with different colors from different burning objects. Another interesting preconception of students is the belief that structure of incandescent lava is the same as Sun's structure (INCSUN). Although, surface of Sun is incandescent and radiation from it is a typical thermal radiation, inner structure of Sun is not really the same as incandescent lava from Earth's inner layers. Moreover, some students stated that thermal radiation of an incandescent object stops when it gets cold because it becomes an opaque solid (BECOPAQ). Up to now, these preconceptions seem to be based on daily life observations of apparent similarities among incandescence, combustion and solar radiation. On the other hand, one more preconception was observed and defined which does not seem to be related to daily life situations. In this context, some students expressed that the vibrations of particles in an object stop when it is frozen (STOPVIB). Instead of being observational, this is rather a theoretical preconception probably based on the false idea that particles in solids cannot move due to solidity.

Open-ended questions about blackbody radiation were re-implemented after implementation of comic story. Some examples of student's answers to these questions before and after the implementation are available in Table 4 below.

Table 4. Examples of students' answers to open-ended questions about blackbody radiation before and after implementation

Question	Answers before implementation	Answers after implementation
QBR1	Lava emits light when it comes to the surface because it is burn when it meets with air.	Lava emits light because of the movements of charged particles in it.
QBR2	Lava stops emitting light when it gets cold because it becomes an opaque solid.	Lava stops emitting light when it gets cold because movements of charged particles stop.
QBR3	-	The source of emission is atoms at smallest scale.
QBR4	Type of matter determines the color of the light emitted by an incandescent object.	Temperature determines the color of the light emitted by an incandescent object.
QBR5	Light is both a wave and a particle.	Light is composed of energy packages called photons.

As seen in the Table 4 above, students have correct, partially correct and wrong answers in both implementations. In addition, it was observed that students' wrong answers evidently decreased after the implementation of comic story. Nevertheless, answers of some students to QBR2 seemed to be evolved from a wrong to another kind of wrong. In other words, the comic story seemed to contribute the formation of the false idea stating that an incandescent object stops emitting light when it gets cold because movements of charged particles stop. Additionally, after reading comics, wave nature of light seemed to be highlighted less in the answers to QBR5. This finding indicated that comic story might distribute a wrong idea of light having only particle properties.

Results from Opinion Form

Students answered a series of open-ended questions in the opinion form after implementation of comics. Their answers to these opinion questions were analyzed via qualitative content analysis based on the process of coding and categorizing similar answers. Table 5 summarizes the results of qualitative content analysis of students' answers to opinion questions.

Table 5. Summary of the results from opinion form

Category	Explanation
QSO1	What are the problems of modern physics course?
DIFFCOM	I have difficulties in comprehending modern physics concepts.
LACKEXP	There is a lack of laboratory activities in modern physics course.
BORING	Modern physics course is boring.
LACKEXA	Not enough daily life examples are given in modern physics course.
QSO2	What do you like in the comic story that you just read?
LIFEEXA	I liked comic story because it consists of a daily life example.
INFLANG	I liked comic story due to its informal language.
COMPRE	I liked comic story because it is easily comprehensible.
ENTERT	I like comic story because it is entertaining.
QSO3	What do not you like in the comic story that you just read?
INFUFFINF	The amount of information included in the comic story is insufficient.
QSO4	What are the benefits of this approach?
LONGTERM	Comics may cause long-term learning.
MAKESIMP	Comics help learning by simplifying the concepts.
MAKEINT	Comics help learning by making modern physics course more interesting.
MAKEFUN	Comics help learning by making modern physics course funnier.
QSO5	What are disadvantages of this approach?
LOWLEV	Comics are more appropriate for lower level concepts.
QSO6	How can comics be integrated to modern physics course?
-	-
QSO7	How can this approach be improved?
ANIMAT	Comics may be converted into animations.
MOREHUM	Comics should consist of more humor.

In the opinion form, QSO1 is the question asking students' opinion about the problems in modern physics course. Many students stated that they have difficulty in comprehension of modern physics concepts (DIFFCOM). Students explained DIFFCOM with the associating keywords such as, abstract, complex, illogical, brain racking and unimaginable. In addition, many students reported the lack of experimental applications during modern physics lessons (LACKEXP). Actually, modern physics course in science education program, at which all of the participants are studying, is defined as a theoretical course. Therefore, it may be suggested to re-design the modern physics course with laboratory activities. Moreover, a number of participants expressed that modern physics course is boring (BORING). They explained BORING mostly with the lack of variety of teaching methods in the course, which means that modern physics concepts are mostly taught through verbal content without using visuals. Students also expressed that daily life examples of modern physics concepts are not given sufficiently during the instruction (LACKEXA). Actually, LACKEXA is somehow an inevitable situation because of the nano-scale nature of modern physics concepts. However, technological examples may be helpful in the teaching/learning process, such as cathode tubes in TV receivers or light sensors of the automatic doors.

The question QSO2 in the opinion form is asking students' positive opinions about the comic story implemented. A number of students reported that they like the comic story because it includes a daily life example in it (LIFEEXA). Actually, students seemed to enjoy the explanation of blackbody radiation with respect to ceramic pottery example. In addition, some students stated that they enjoy informal language used in the comic story (INFLANG). Some of them expressed that they like informal language in the comic story due to dialog style narration consisting a series of questions and answers. Moreover, some students reported that the comic story that they read is comprehensible (COMPRE). To explain COMPRE, they used keywords such as, short, plain, clear, simple and summary. Additionally, the participants seemed to find comic story entertaining (ENTERT) by using keywords such as, humorous, funny, interesting and not boring. Literally, this is an expected situation, comics are among common media that are carrying humor and entertainment.

In the opinion form, QSO3 is the question asking students' negative opinions about the comic story implemented. It was observed that most of the students did not answer this question.

According to some students, the amount of information included in the comic story is insufficient (INSUFFINF). This opinion may be related to their expectation about complicated mathematical explanations of the modern physics concepts. In addition, students may not be familiar with any kinds of conceptual explanations.

In the opinion form, QSO4 is the question about the advantages of using quasi-historical comics in learning modern physics concepts. According to some students, the comic story helps learning through making modern physics concepts simpler (MAKESIMP). They explained this opinion with the phrases in their answers such as, simplifying the concepts, making them plain and making them concrete. In addition, some students stated that comics might cause long-term learning (LONGTERM), due to their context-based and visual nature. This finding is especially important because the participants just feel or predict long-term learning although the implementation is not long-term. Additionally, according to some students, comics contribute learning modern physics concepts by making the course more interesting (MAKEINT). They explained their answers with the keywords such as, curiosity, eagerness and attractive. Moreover, some students thought that comics help learning by making lessons funnier (MAKEFUN). They described this opinion with the phrases, such as enjoyable and pleasure.

In the opinion form, QSO5 is the question about disadvantages of using quasi-historical comics in modern physics course. It was found that most of the students did not respond this question. According to some participants, comics are more appropriate for lower level concepts (LOWLEV). Some of them reported that comics are not suitable for undergraduate level or they are not appropriate for difficult concepts like ones in modern physics course.

In the opinion form, QSO6 is the question about the ways of integration of comics in modern physics course. Firstly, only a few students answered this question. It was also observed that the individual answers to this question are not similar to each other. In other words, any apparent patterns to be coded were not observed for this question. Therefore, any categories were not defined for the answers to this question. However, the most interesting individual answer is that “students may create their own comics” which may be interpreted as the expectation about the integration of comics into the instructional process with a more interactive way, instead of being just a reading activity.

In the opinion form, QSO7 is the question about the ways of improving comics for modern physics course. Some students stated that comics might be improved by converting them into animations (ANIMAT). Students seemed to prefer dynamic media that they are more familiar with. Additionally, some of the students suggested that comic story should have more humor (MOREHUM). Comics are published mostly on humor magazines and this situation may create the expectation of extra humor in the comic story implemented.

Results from Interviews

As mentioned in the method section, a semi-structured interview with two participants were performed after one week from the implementation of comic story. After a quick descriptive analysis of written answers to the opinion forms, two participants one of who had positive opinions and the other one of who had negative opinions were selected in order to seek deeper information. The same questions as the ones in the written opinion form were asked them in separate sessions. Both of the participants seemed to have similar opinions about the difficulty, boringness and fearsomeness of modern physics courses. The participant who is having mostly positive opinions said that humorous comic story made reading about modern physics more entertaining. She also said "it has contribution to learn blackbody radiation, now I do not remember the formula but I remember the comics". However, the participant who is having mostly negative opinions said that instructional comics are not appropriate for undergraduate level. She also said "I found it childish, instead of it, I prefer doing experiments". It seems that the instructional comic story made some students more willing to read about modern physics, however it was not perceived as an activity serious enough for modern physics course by some other students.

Conclusion

To sum up, it was observed that participants found modern physics course difficult and boring without laboratory activities and daily life examples. These findings seem to be similar with the ones in the literature (Baily & Finkelstein, 2010). It was also observed that students have several preconceptions about blackbody radiation such as “incandescence is burning in the air” and “color of light from an incandescent object is depend on type of matter”. In addition, it was found that students’ wrong answers evidently decreased after the implementation of quasi-historical comic story. Students seemed to enjoy instructional comic story due to its context-based nature, entertaining atmosphere and informal language. In addition, they thought that the comic story contributes learning by simplifying the modern physics concepts. They also thought that comics may cause long-term learning due to their context-based and visual nature. These views seem to be parallel with the related literature (Liu, 2004; Tatalovic, 2009; Jee & Anggoro, 2012), however students seemed to perceive the comic story only as a medium. They did not report any opinions about the quasi-historical content of it. Therefore, it may be concluded that medium characteristics of comic story (e.g. funny drawing style and daily life language) seem to dominate content characteristics of it. With respect to these findings, it was concluded that using comics as an instructional medium in undergraduate modern physics course may contribute to learning modern physics concepts. However, for the revisions of this comic story and the development of new instructional comics, some design considerations were noted with respect to students’ opinions and suggestions. For instance, visual and contextual design of the instructional comics should be appropriate for the target age, there should be more connections to daily life situations and scenario should include more humor. This study focused on designing, developing and small-scale implementation of a quasi-historical comic story about blackbody radiation to get feedback for revisions. For further research, it is suggested that large-scale implementation with quantitative data analysis may be performed in order to draw general conclusions about the usage of instructional comics in modern physics courses.

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Appendix A

English Translation of Text in the Comic Story

Title: Blackbody Radiation: Birth of The Quantum Atom

Panel 1: Berlin, 1900

- Have you read Planck's latest article? Everyone says that his theory is completely in contrary to physics.

Panel 2:

- Yes, it is. Planck explains blackbody radiation in a strange way.

- I am not a physicist, tell it to me in a way that I can understand, please.

Panel 3:

- Ok, listen. Clay pot makers predict the temperature of the kiln by watching the color of light from a small hole on it. We call this hole as blackbody in physics.

Panel 4:

- When the kiln is cool, the hole is black. However, while the kiln is being heated, a reddish light starts leaking from the hole.

Panel 5:

- I think it is not so strange. While the kiln is being heated, contents in it become incandescent and emit light. Then, some of this light leaks from the hole.

Panel 6:

- You are right. However, for instance, when we measure wavelength and intensity of light at 1500 degree, we observe that infrared light has very high intensity, ultraviolet light has very low intensity.

Panel 7:

- At this temperature, hole is seen reddish, because red and orange lights among visible colors are emitted more brightly than the others.

- So, what is the source of all these light with different wavelengths?

- 35 years ago, Maxwell showed that the source of radiation is moving charged objects.

Panel 8:

- Therefore, kiln should be composed of charged particles and these particles emits light while oscillating.

- I think, these particles should be invisibly tiny.

Panel 9:

- Yes, exactly. We think that these particles emit light at various wavelengths while the kiln is heated. However, we can not explain why these particles emit purple and ultraviolet light very limitedly.

Panel 10:

- It is really interesting. So, what is Planck's suggestion to solve this problem?

Panel: 11:

- Planck claims that these particles emit light at only some certain oscillations. Number of oscillations that allow emissions of blue, purple and ultraviolet light with high energy are limited. Therefore, the intensity of these wavelengths is quite low.

Panel 12:

- Planck calls these particles as oscillators and he states that lights emitted by oscillators are energy packages rather than being waves as in Maxwell's view. He calls these energy packages as quanta.

- Oscillating particles emitting energy packages at only certain oscillations… Really, physics is being weird.

Footer:

A few years later, Planck's oscillator were called as atoms and quanta were called as photons. This area of physics explaining atoms was called quantum mechanics.