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The Effect of Context-based Comics on Sixth-Grade Students' Grounded Mental Model Development*

Bağlam Temelli Çizgi Romanın Altıncı Sınıf Öğrencilerin Temellendirilmiş Zihinsel Model Gelişimine Etkisi

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ABSTRACT: The research examined the effect of context-based comics on the grounded mental model (GMM) development of sixth-grade students. Fifty-nine students were included in the study, which was conducted with a quasi-experimental design. A context-based comic (CbC) was used to teach the experimental group, whereas the course was taught using existing textbooks in the control group. As a data collection tool, the context-based learning situations test (CbLST) for electrical conduction was applied as a pre-and post-test. As a result of the research, it was concluded that the learning environment designed in the experimental group had a greater effect on GMM development than the control group and that the CbC was an effective teaching material in GMM development compared with the current textbook. Based on these results, the use of CbCs and the determination of GMMs in science teaching should be increased. Recommendations have also been made regarding the use of CbLSTs.

Keywords: Comic books, conducting electricity, context-based learning, grounded mental model.

ÖZ: Araştırmada, bağlam temelli çizgi romanın altıncı sınıf öğrencilerin temellendirilmiş zihinsel model (TZM) gelişimine etkisi incelenmiştir. Yarı deneysel desene göre yürütülen araştırmaya 59 öğrenci dahil edilmiştir. Deney grubunda bağlam temelli çizgi roman (BTÇR) ile kontrol grubunda mevcut ders kitabı destekli dersler işlenmiştir. Veri toplama aracı olarak bağlam temelli elektriğin iletimi öğrenim durumları (BTÖDT) testi ön-son test olarak uygulanmıştır. Araştırma sonucunda deney grubunda tasarlanan öğrenme ortamının kontrol grubuna göre TZM gelişimine etkisinin daha fazla olduğu ve BTÇR'nin mevcut ders kitabına göre TZM gelişiminde etkili bir öğretim materyali olduğu sonucuna ulaşılmıştır. Araştırma sonuçlarına göre TZM teorisinin kullanarak öğrencilerin zihinsel model tespitinde pratik bir şekilde tespit edilebileceği ve öğrenme ortamlarını ona göre düzenlenebileceği önerilmiştir. Ayrıca BTÖDT ve BTÇR kullanımına ilişkin öneriler sunulmuştur.

Anahtar kelimeler: Bağlam temelli öğrenme, çizgi roman, elektriğin iletimi, temellendirilmiş zihinsel model.

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Given that the aim of science teaching is to make sense of nature (Karslı-Baydere & Aydın, 2019), such teaching should be a process that is intertwined with students' everyday lives. In this sense, context-based teaching practices have been reported to be effective. The meaning of 'context' in teaching refers to how students make sense of classroom activities and content (De Jong, 2006). Students may have incomplete or incorrect learning of science teaching practices because scientific concepts are not sufficiently connected to their daily lives (Gömleksiz & Bulut, 2007; Barker & Millar, 1999; Yager & Weld, 1999).

Science is a difficult subject to learn (Nurhumairah & Handayani, 2024). In this regard, several problems can arise in science education. Research shows that most students find it difficult to learn basic concepts and relate them to their daily lives. One of the main reasons for this problem is that science education does not relate scientific concepts to students' real lives or give them contexts to use these concepts in their daily lives (Pilot & Bulte, 2006).

Electricity is one of the most difficult subjects to teach in science education (Mırçık, 2018). Students find it difficult to understand concepts related to electricity and to relate them to their daily lives (Ateş & Polat, 2005; Çıldır & Şen, 2006). The common goal of studies on electricity and different teaching practices in the literature is how students can gain a better understanding of the topic of electricity, which has increased academic success (Ivanjek et al., 2021; Kallunki & Lavonen, 2010; Karslı-Baydere & Bülbül, 2021; Lin, 2017;). It has been reported that students at almost all educational levels show incomplete learning and have difficulties in understanding the topic of electricity and relating it to their daily lives (e.g., Chambers and Andre, 1997; Hussain et al., 2013; Kapartzianis & Kriek, 2014; Şengüleç et al., 2017; Villarino, 2018). Therefore, a new understanding of the teaching of electricity is needed. In this sense, this study investigates the effectiveness of context-based comics (CbCs) on grounded mental models (GMMs) in teaching electricity. For this purpose, different definitions of the context-based learning (CbL) approach, comics and GMMs are presented below.

Context-Based Learning (CBL) Approach

For science teaching to be meaningful, concepts must be concrete and related to students' lives (Akgün et al., 2016; Coştu & Ayas, 2005). CbL can be seen as a solution to the problems of learning deficits in science education, its lack of connection to everyday life, and students' inability to make sense of scientific concepts (Glynn & Koballa, 2005). As science often involves difficult concepts, the CbL approach can help to overcome these problems. The CbL approach shows students where the topics they are learning can be used in everyday life by providing contextual examples (Clifford & Wilson, 2000).

With the CbL approach, students can transfer their scientific knowledge to their daily lives and learn science subjects in a meaningful way (Bennett & Holman, 2003; Ünal, 2008). CbL brings everyday problems into the classroom (Parnell, 2001) and establishes a connection between the scenarios it contains, the students' environment and theoretical knowledge (Gökçe, 2018). The contexts used in CbL materials are sample situations from the students' environment. Through these contexts, students establish relationships between the scientific information they are learning and their daily lives (Yıldırım & Gültekin, 2017).

It is more meaningful to evaluate the science teaching activities carried out through CbL with a measurement tool specifically designed to evaluate this approach (Elmas & Eryılmaz, 2015). Evaluating teaching activities according to CbL with traditional questions may lead to a lack of connection between everyday life and science (Benckert, 1997). Therefore, it may be better to use questions prepared on the basis of CbL to assess how students have learned to apply science to their daily lives through context-based questions. Contextual questions pose problems that students are expected to solve by drawing on their knowledge of topics or concepts from their everyday lives (Bennett et al., 2007). In other words, it is important to determine the extent to which students can transfer their scientific knowledge. Comics can be used as part of a CbL approach to course design. Through comics, contexts related to students' everyday lives can be brought into the learning environment.

Comics

Comic books are among the teaching materials that can be used in learning environments to make abstract topics more concrete, increase students' interest and motivation, make it easier for them to relate scientific knowledge to everyday life, and make lessons more entertaining (Hutchinson, 1949; Greenfield, 2017; Şentürk-Çiçek, 2020; Yüzbaşıoğlu & Kurnaz; 2024; Wijayanti et al., 2024). Comics have an enriching effect on the classroom environment (İlhan & Şin 2024). They can increase students' interest and motivation in science education (Lazzarich, 2013). Comics present visual elements and text together in harmony. Their humorous elements make lessons more entertaining (Hosler & Boomer, 2011). Supporting science subjects with graphic images can enable students to learn more meaningfully (Cheesman, 2006; Hosler & Boomer, 2011; Topkaya & Doğan, 2020; Yüzbaşıoğlu, 2022). Comics can also improve learning outcomes (Miarsyah et al., 2024).

The use of comic books as teaching materials can make students more willing to look at them outside of class, increase their motivation and make learning more permanent (Hosler & Boomer, 2011; Şentürk-Çiçek, 2020; Wood, 2015). Comics can increase students' interest in reading and their interpretive skills by fostering a sense of curiosity (Wood, 2015). Because comics allow students to participate in the learning process, they can enable them to take responsibility for their learning (Cheesman, 2006). Comics can also support making connections between the learning environment and everyday life through the scenarios and stories they contain (Cheesman, 2006).

Comics created using contextual situations that are familiar in students' lives can lead to students 'seeing' themselves in the comics and forming emotional bonds with the characters they read about (Cheesman, 2006; Williams, 2008). Science topics can be addressed through comics and prepared using the CbL approach. Thus, comics can be used as effective teaching materials in science classrooms, helping students to structure scientific knowledge in their minds in a meaningful way (Yüzbaşıoğlu, 2022).

Grounded Mental Models (GMMs)

Simplified representations of difficult and complex information are called models. Models help to structure scientific knowledge (Güneş & Çelikler, 2009) and thus build bridges between the mind and the real world (Hubber, 2006). The cognitive representations that students use to make sense of the real world can be referred to as Mental Models (MMs) (Franco & Colinvaux, 2000). MMs are the structures that students use to explain the structures in their minds. Just as each student's MM is different, their MMs can change as they interact (Greca & Moreira, 2001). As MMs are students' internal representations, they can be understood and determined by their relationship to students' observable behaviour (Rapp, 2005). Identifying MMs is important in the learning process because organising the learning environment according to students' MMs will contribute positively to teaching (Chi, 2013; Michael, 2004).

Many tools have been used to determine students' MMs (Kurnaz & Ekşi, 2015; Yüzbaşıoğlu & Kurnaz, 2020). Open-ended questions, drawings, and interviews are often used to assess students' MMs (e.g., Hamdiyati et al., 2018; Hermita et al., 2021; İyibil & Sağlam Arslan, 2010; Vosniadou & Brewer, 1992; Yüzbaşıoğlu & Kurnaz, 2020). However, the analytical processes are difficult and tedious for researchers when analysing the data obtained through these instruments. Furthermore, given the variability of MMs and the time-consuming nature of the analysis, it is not easy or practical to organise learning environments according to students' MMs. To overcome these difficulties, well-structured data collection tools should be used to identify students' MMs.

The idea that students' MMs can be determined with data collection tools via well-structured multiple-choice questions based on the literature was put forward by Kurnaz (2012, 2018; 2019) and transformed into the GMM theory. According to Kurnaz's (2022) theory, the GMM can be practically determined via well-structured data collection tools within a specific framework presented to the student. The GMM theory begins by accepting the basic MM theory and establishing a new field of study. In other words, the principle of compatibility between GMM and MM theories (the principle of equivalence) is semantically valid. One of the basic assumptions of the GMM is that when students choose one of the options offered, the choice chosen represents the student's mental structure or is the most appropriate, and this information is useful in teaching processes; it is practical information. The possibility of giving unlimited answers is not offered when determining the GMM, which creates new analytical possibilities for the GMM. Moreover, it is advantageous to make the LST functional and practical in the face of the difficult process of determining MMs, and this provides opportunities for organising learning environments. A learning situation test (LST), consisting of multiple-choice questions, determines the GMM, which is different from the traditionally used achievement tests. In the LST, there are three options: the scientific (correct) answer, an incorrect answer (with alternative ideas), and a null answer (Ezberci-Çevik, 2018; Ezberci &Kurnaz, 2022; Kurnaz, 2022; Yaz, 2022; Yüzbaşıoğlu, 2022; Yüzbaşıoğlu & Kurnaz, 2024). Furthermore, there is no limit to the number of choices for a question, as all possible answers in the literature are expected to be included in the incorrect or null choices. Thus, when determining the GMM, it is possible to evaluate all responses holistically, rather than coding student responses as true or false. In addition, the inclusion of all possible

This study therefore addressed the following research question

"What is the effect of using a CbC on the topic of electrical conduction on students' development of GMMs?"

Method

The research was quasi-experimental, with pre- and post-tests and experimental and control groups. In experimental designs that include variables as influencing factors, it may be possible to establish a cause and effect relationship between variables (Fraenkel et al., 2012; Mertens, 2015). This type of research examines the changes caused by independent variables. For this reason, in the present study, the independent variable was the CbC prepared for teaching the topic of electricity. The dependent variables were the changes in the students' GMMs. The experimental and control groups were determined impartially. Since the experimental and control groups were not determined null, the study was conducted according to a quasi-experimental design (Fraenkel et al., 2012). The process of the quasi-experimental application used in this research is shown in Table 1.

Table 1

Quasi-Experimental Application

Group	Pretest	Application	Posttest
Control	X	Current/Ordinary learning environment	X
Experiment	X	A context-based approach using a designed learning environment	X

Study Group

The study group consisted of sixth grade students enrolled in a public middle school in the Western Black Sea region of Turkey. The study group was selected using convenience sampling. Convenience sampling is selected based on the objectives of the research, the characteristics of the population, and the requirements of the study. A total of 59 students participated in the research, with 27 students in the experimental group and 32 students in the control group, each from different classes. Convenience sampling is a method in which the study group is determined according to criteria that are voluntary, accessible, appropriate and achievable (Dörnyei, 2007). Information about the study group is given in Table 2.

Table 2

Study Group Students

Group	Gender		Total
	Female	Male	
Experimental	7	20	27
Control	16	16	32

Experiment Application

The experimental and control groups were students from the same public secondary school. The same science teacher taught both experimental and control groups. The experiment was designed so that the only difference in the learning environment between the experimental and control groups was the use of a CbC. This CbC was used to teach the topic of electrical conduction. After the experimental group had been taught using the CbC, the changes in the students' GMMs were examined. The control group was taught according to the curriculum, using the activities from the textbook. After teaching, the GMMs of both the experimental and control groups were examined. In both groups, the teaching was carried out over three weeks, consisting of 12 lessons, according to the curriculum.

A CbC on the conduction of electricity was used for the experimental group's teaching practice. The CbC development process started with the identification of students' alternative ideas and conceptual difficulties on the target topic (conduction of electricity). First, literature was reviewed and scenarios were prepared by selecting content that was compatible with student level and teaching objectives. 178 science teachers across Turkey were contacted to collect contextual suggestions and examples on the topic, and the appropriate ones were integrated into the scenarios. According to the scenarios, a comic book format design was created using the Storyboard That programme. Initial design adjustments were made according to the expert opinions and final design adjustments were made according to the pilot application results, and the CbC took its final form. In the experimental group, the CbC was used instead of the textbook in the normal teaching processes. A section of the CbC is shown in Figure 1.

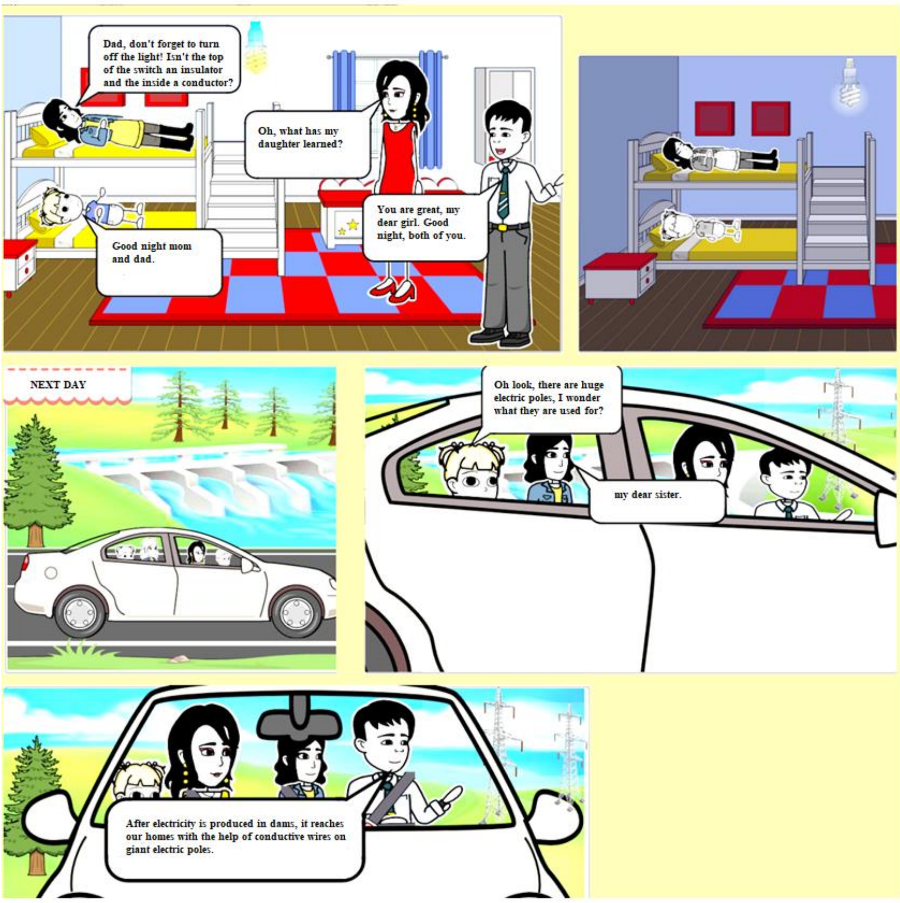

Figure 1. A Section of the CbC

Data Collection Tools

A context-based LST (CbLST) was used to determine the GMM. The purpose of a CbLST is to measure learning situations, not academic performance. It is a data collection tool structured by the researchers during the first researcher's doctoral studies and was used as a data collection tool in this study. This test consisted of questions about electrical resistance, conductors and insulators. In order to prepare the CbLST, the first step was to analyse the literature and, in particular, to identify students' alternative ideas and Aristotelian views on the topic. In this step, contextual suggestions were also collected from the teachers, and then questions were prepared. Secondly, expert opinion was sought on the draft questions and 32 questions were identified. Finally, these questions were administered to 293 students as a pilot study and the item difficulties were calculated. Easy and difficult questions were removed and the test was composed of items of medium difficulty. As a result, a final 21-item GMM detection test was developed (for further details see Acet 2024; Acet & Kurnaz, 2025). An example question from the CbLST is given below.

Question	Choices		Choice quality
 Osman is tasked with lighting the countryside wedding of Osman's brother. Excitedly accompanying Master Basri in installing many bulbs, Osman realized that the bulbs did not illuminate enough when he turned on the switch in the evening and was upset. Osman was very happy when Master Basri, who saw him sad, said he should not be sad and could solve this situation. Which of Osman's comments about this situation is correct?	A	The reason why the illumination is not sufficient may be that the resistance needs to be higher.	Alternative idea
	B	Only the number of bulbs used can be increased for better lighting.(Brna, 1988).	Alternative idea
	C	The bulbs can be connected higher to ensure sufficient illumination.	null
	D	Using thicker conductor wire can increase the brightness of the bulb.	Scientific
	E	Electric energy can flow faster in a shorter wire. (Küçüközer, 2004; Keser & Başak, 2013).	Alternative idea
	F	Thin wires may resist the passage of electricity more than thick wires. (Villarino, 2018; Keser & Başak, 2013).	Alternative idea
	G	Since light bulbs consume electrical energy, they may not be enough for others. (Küçüközer, 2004).	Alternative idea
	H	The brightness of light bulbs has nothing to do with electrical resistance (Hussain et al., 2013).	Alternative idea

The choices for the items were the correct scientific answer, incorrect answers (containing alternative ideas) and null answers (containing Aristotelian views). In the example question above, choice D is scientific, choice C is null, and choices A, B, E, F, G and H are incorrect answers. The incorrect choices were created from alternative ideas found in the literature. The CbLST choices have thus been prepared on the basis of an extensive literature review. The large number of choices is intended to allow an answer that is closest to the cognitive representation in the student's mind, and in this respect it differs from the achievement test. There are 21 questions in the CbLST. Each question has different possible answers: a correct answer, incorrect answers (with alternative ideas) and null answers. Data were collected from the CbLST as a pre-post test, i.e. before and after the teaching of the experimental and control groups.

Data Analysis

The mind can be thought of as a Euclidean space in which the components of how a concept is understood can be the scientific answer, incorrect answers, and null answers to questions about that concept (Kurnaz, 2022). The correct, incorrect and null answers can be thought of as the x, y and z dimensions. According to Kurnaz (2022), when determining the GMM, multiple questions should be asked in order to understand how the target concept is cognitively structured in the individual, and students should be given access to all possible answers that they might be able to answer a question to the greatest extent possible. The GMM is then determined to be as close as possible to each student's current GMM. This is done by looking at the result of all the answers the student gives to a question.

The first task in analysing the data is to encode the answer to each question as a unit answer vector. This coding is as follows: the correct answer is marked (1, 0, 0), the wrong answer is marked (0, 1, 0) and the null answer is marked (0, 0, 1). The unit response vectors obtained from a randomly selected data set and the resulting response vector obtained from it are given as an example in Table 3.

Table 3

Example of a Determining Unit and the Resulting Response Vectors

Question	Type of Answer			Student's answer	Response Vector	Resultant Answer Vector
	Scientific (i)	Incorrect (j)	Null (k)			
1	B	A, D, E	C	B	(1 0 0)	(1 2 1)
2	C	D, E, F, G	A, B	E	(0 1 0)	
3	D	B, E, F	A	A	(0 0 1)	
4	A	C, D, E	B	D	(0 1 0)	

As shown in Table 4, the GMM vectors for each student's responses can be determined. When more than one question is asked on the target topic/concept, the unit contribution of each question is considered. To do this, the student response vectors and the unit vectors (i, j and k) of each student's responses to each question are determined. Next, the resultant vector (C_k) of the student responses belonging to the group of questions related to the target topic/concept is determined. Given that the inner product of two vectors is a real number and that the inner product of a vector with its transposition is equal to the square of the norm, the vector C_k representing the answer to a question (satisfying the norm/length condition -1-) is determined as follows.

$$C_k = \begin{pmatrix} \sqrt{i} \\ \sqrt{j} \\ \sqrt{k} \end{pmatrix}$$

The formula below determines the 'resultant vector' for all the answer vectors of the entire question group. In the formula 'ss' refers to the number of questions. The resultant vector for the sample student's four-question group in Table 3 is calculated as follows.

$$C_k = \frac{1}{\sqrt{ss}} \cdot \begin{pmatrix} \sqrt{x} \\ \sqrt{y} \\ \sqrt{z} \end{pmatrix} C_k = \frac{1}{\sqrt{4}} \cdot \begin{pmatrix} \sqrt{1} \\ \sqrt{2} \\ \sqrt{1} \end{pmatrix}$$

The GMM density matrix (Dk) is derived from the vector Ck and its transpose. The calculation example and the formula for the example student are given below.

$$D_k = \frac{1}{ss} \begin{bmatrix} x & \sqrt{xy} & \sqrt{xz} \\ \sqrt{yx} & y & \sqrt{yz} \\ \sqrt{zx} & \sqrt{zy} & z \end{bmatrix} D_k = \frac{1}{4} \begin{bmatrix} 1 & \sqrt{2} & \sqrt{1} \\ \sqrt{2} & 2 & \sqrt{2} \\ \sqrt{1} & \sqrt{2} & 1 \end{bmatrix} = \begin{bmatrix} 0{,}25 & 0{,}35 & 0{,}25 \\ 0{,}35 & 0{,}50 & 0{,}35 \\ 0{,}25 & 0{,}35 & 0{,}25 \end{bmatrix}$$

The matrix determined is the GMM density matrix, which can be assigned on the basis of the diagonal elements of the matrix. The classification of the meanings of the matrices to be determined is given in Table 4.

Table 4

GMM Classification According to the Individual Density Matrix (Kurnaz, 2022)

Scientific Model (SM)	The first diagonal element is 1 must (e.g., 800 or 900).
Scientific Dominant Model (SDM)	The first diagonal element, another diagonal from the elements big to be, and other elements almost none must be (e.g., 800 or 710).
Non Scientific Model (NSM)	The second diagonal element is another diagonal from the elements bigger to be, other elements almost none to be must (e.g., 260 or 071).
Inconsistent (Mixed) Model (IMM)	Fly diagonal elements each other close to values owner to be, other elements relatively from scratch big to be must (e.g., 332, 323 or 233).
Primitive Dominant Model (PDM)	The third diagonal element is another diagonal from the elements big to be, other elements almost none to be must (e.g., 107 or 026).
Primitive Model (PM)	The third diagonal element is one must (e.g., 007 or 006).

Table 4 considers six ways of determining a student's GMM. Accordingly, the GMM of the example student examined above is an inconsistent mixed model (IMM). Analyses can be performed individually or for a population. For example, the class density matrix can be used to determine the GMM tendencies of the student group. However, it is not the GMM of the class that is of interest, but the trend of the GMM. The following formula determines the class density matrix, where 'N' is the number of pupils.

$$D = \left(\frac{1}{N}\right) \sum_{k=1}^{N} D_k$$

The matrices obtained for each student are used to determine the GMM tendencies of the class, and the tendencies are evaluated in three groups according to the following matrices (Kurnaz, 2022):

Table 5

Mass GMM Trends and Criteria

Disposition	Explanation	Example		
Consistent	Students in the group place area are approximately the same as the GMM owner tends to be. For example, the form can show 0.95 -0.03-0.02, 0.15-0.66-0.19, 0-0.01-0.99, etc., distribution in the form. In examples seen like students GMM’s scientific, incorrect answer or null in the answers clustered.	1 0 0 0 0 0 0 0 0	0 0 0 0 1 0 0 0 0	0 0 0 0 0 0 0 0 1
Consistent Mix	Students in the group place area are a few different from GMM. However, GMM is only for every student. This is a consistent mixed trend aspect expression is done.	0.77 0 0 0 0.20 0 0 0 0.03	0.49 0 0 0 0.50 0 0 0 0.01	0.05 0 0 0 0.30 0 0 0 0.65
Inconsistent Hash	Students in the group place are students different from GMM's. However, students' GMM is consistent because it is not. This situation is an inconsistent mixed trend aspect expression. Well, diagonal elements all from scratch should be	0.20 0.38 0.12 0.38 0.73 0.22 0.12 0.22 0.07	0.38 0.39 0.17 0.39 0.49 0.23 0.17 0.23 0.13	0.20 0.38 0.12 0.38 0.73 0.22 0.12 0.22 0.07

Validity and Reliability Studies

In developing the CbC and CbLST, suggestions for appropriate contexts were collected from 178 science teachers across Turkey. The comic strip and the questions used in the data collection tool provide examples of how teachers related the learning outcomes required in the Conduction of Electricity unit to everyday life. An example of a teacher's suggestion for a context is given in Table 6.

Table 6

A Teacher's Outcome Context Attribution example

Learning outcome	F.6.7.2.2. Being able to define electrical resistance. Which situation/event from your daily life do you associate this gain with? Give an example or examples.
Context	While a garden hose performs its irrigation function well under normal conditions, the water flow slows down or stops completely when the hose is folded in one or two places.

Opinions were obtained from six experts on the appropriateness of the items created for the study in terms of suitability for acquisition, comprehensibility and clarity, suitability for contextualization and suitability for research, and language and expression. After expert review and subsequent revision, a pilot administration of the test was conducted. The test was administered to 293 sixth grade students, with all necessary permissions obtained in advance. In order to assess the effectiveness of the CbC as course material, expert feedback was obtained on its alignment with learning outcomes, clarity of language and expression, and contextual appropriateness. Opinions were obtained from six experts: three science educators, one programmer development expert and one language and expression expert. In line with these opinions, corrections were made to the context-based comic book that was ready for pilot use. The characters are introduced in the introduction section of the developed context-based comic book. Before finalizing the CbC, the pilot application was carried out with 17 sixth grade students. The opinions of the course teacher and the students about the comic book were obtained, and the final version was created after editing.

Ethical Procedures

This research was conducted with the permission obtained from the Kastamonu University Rectorate Social and Human Sciences Research and Publication Ethics Committee, dated 17.05.2022, with the decision numbered 9 of the evaluation document.

Results

The CbLST consisted of sets of questions on 'Conductors and Insulators' and 'Electrical Resistance'. Each student was analysed separately as described in the data analysis section. For example, the uncovering process of the GMM of Student 7 (S7) in the control group was as follows: S7 gave one correct, seven incorrect and zero null answers to the eight-item question set 'Conductors and Insulators'. Therefore, S7's 'resultant vector' for all answer vectors was (1 7 0). S7's Ck was as follows.

$$C_k = \frac{1}{\sqrt{ss}} \cdot \begin{pmatrix} \sqrt{x} \\ \sqrt{y} \\ \sqrt{z} \end{pmatrix} C_k = \frac{1}{\sqrt{8}} \cdot \begin{pmatrix} \sqrt{1} \\ \sqrt{7} \\ \sqrt{0} \end{pmatrix}$$

Then, the D_k calculation for S7 was performed.

$$D_k = \frac{1}{ss} \begin{bmatrix} x & \sqrt{xy} & \sqrt{xz} \\ \sqrt{yx} & y & \sqrt{yz} \\ \sqrt{zx} & \sqrt{zy} & z \end{bmatrix} D_k = \frac{1}{8} \begin{bmatrix} 1 & \sqrt{7} & \sqrt{0} \\ \sqrt{7} & 7 & \sqrt{0} \\ \sqrt{0} & \sqrt{0} & 0 \end{bmatrix} = \begin{bmatrix} 0.13 & 0.33 & 0.00 \\ 0.33 & 0.88 & 0.00 \\ 0.00 & 0.00 & 0.00 \end{bmatrix}$$

The GMM of S7 was identified as a non-scientific model (NSM) because the second diagonal element was greater than the others, the third diagonal element was zero, and the first diagonal element was close to zero. Another example was given to make the analysis more understandable, showing the changes before and after the test. The uncovering process of the GMM of S14 in the experimental group was as follows: In the pre-test, S14 gave five correct, two incorrect and one null answers to the eight-item question group 'Conductors and Insulators'. Then S14's 'resultant vector' for all answers was (5 2 1) and his Ck was as follows:

$$C_k = \frac{1}{\sqrt{8}} \cdot \begin{pmatrix} \sqrt{5} \\ \sqrt{2} \\ \sqrt{1} \end{pmatrix}$$

Then, D_k was calculated for S14.

$$D_k = \frac{1}{8}\begin{bmatrix} 5 & \sqrt{10} & \sqrt{5} \\ \sqrt{10} & 2 & \sqrt{2} \\ \sqrt{5} & \sqrt{2} & 1 \end{bmatrix} = \begin{bmatrix} 0.625 & 0.40 & 0.28 \\ 0.40 & 0.25 & 0.18 \\ 0.28 & 0.18 & 0.125 \end{bmatrix}$$

When analysing the density matrix of S14, since the diagonal elements are greater than zero, the GMM of S14 is determined to be IMM. However, S14's post-test responses were 13 scientific and zero incorrect and null responses. In this sense, S14's 'resultant vector' for all answers was (13 0 0), and his Ck was as follows:

$$C_k = \frac{1}{\sqrt{13}} \cdot \begin{pmatrix} \sqrt{13} \\ \sqrt{0} \\ \sqrt{0} \end{pmatrix}$$

Then, D_k was calculated for S14.

$$D_k = \frac{1}{13}\begin{bmatrix} 13 & \sqrt{0} & \sqrt{0} \\ \sqrt{0} & 0 & \sqrt{0} \\ \sqrt{0} & \sqrt{0} & 0 \end{bmatrix} = \begin{bmatrix} 1.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \\ 0.00 & 0.00 & 0.00 \end{bmatrix}$$

According to the density matrix, since the first diagonal element was 1, the GMM of S14 was determined as the SM. In short, the sample analysis presented for S7 and S14 was carried out separately for all students and in this way the GMM of all students was determined. The changes in the GMM results for the students in the control group in the 'conductor and insulator' question groups are shown in Table 7.

Table 7

Pre-and Post-Test GMMs of Control Group

Student	Pre-Test				Post-Test							
	Conductors and Insulators		Electrical Resistance		Conductors and Insulators				Electrical Resistance			
	NSM	IMM	NSM	IMM	NSM	IMM	SDM	SM	NSM	IMM	SDM	SM
S1		✓		✓		✓				✓		
S2		✓		✓		✓			✓			
S3		✓		✓		✓				✓		
S4		✓	✓			✓				✓		
S5		✓	✓			✓				✓		
S6		✓		✓		✓				✓		

S7		✓			✓		✓				✓		
S8			✓	✓			✓				✓		
S9		✓			✓		✓				✓		
S10			✓		✓	✓					✓		
S11			✓		✓	✓				✓			
S12			✓	✓			✓				✓		
S13			✓		✓	✓					✓		
S14			✓		✓		✓				✓		
S15			✓		✓			✓			✓		
S16		✓			✓		✓				✓		
S17			✓		✓		✓				✓		
S18			✓	✓			✓					✓	
S19			✓		✓	✓					✓		
S20			✓		✓		✓			✓			
S21		✓			✓		✓			✓			
S22			✓		✓		✓			✓			
S23			✓		✓		✓				✓		
S24			✓		✓		✓			✓			
S25		✓			✓		✓				✓		
S26			✓		✓		✓			✓			
S27			✓	✓			✓				✓		
S28			✓		✓		✓				✓		
S29			✓		✓		✓				✓		
S30			✓	✓			✓			✓			
S31			✓	✓			✓				✓		
S32			✓	✓					✓			✓	
T	f	5	27	9	23	4	26	1	1	8	22	2	-
	%	15,63	84,37	28,14	71,86	12,51	81,25	3,12	3,12	25	68,75	6,25	-

SM: Scientific Model; SDM: Scientific Dominant Model; IMM: Inconsistent Mixed Model; NSM: Non-Scientific Model; PDM: Primitive Dominant Model; PM: Primitive Model; T: Total

In Table 7 it can be seen that the GMMs of the students in the control group did not show enough change in the positive direction for both subjects. According to the pre-test results on 'Conductors and Insulators', 15.63% of the students in the control group were classified in the NSM and 84.37% in the IMM. No students were classified in the other GMMs according to the pre-test results. On the other hand, the post-test results showed that 12.51% of them had the NSM, 81.25% had the IMM and 3.12% had the SDM or the SM. No students were classified in the other GMMs. Only one student was classified in the SM model.

The pre-test results on 'electrical resistance' showed that 28.13% of the students in the control group had the NSM and 71.87% had the IMM. After the training, 25% of them had the NSM, 68.75% had the IMM and 6.25% had the SDM. No students were classified on the other GMMs. In particular, it should be noted that no students were classified in the SM. Also, unfortunately, in both subjects, the distribution of the students' IMM is intense both before and after the training.

The presence of the NSM and IMM before training, and the continued intensity of these models after training, suggests that students continue to have difficulty reconstructing their conceptual understanding in a meaningful way. This implies that the training intervention was not sufficiently effective in facilitating conceptual change in the control group. In this context, it can be noted that there was very little change in the GMMs. The results suggest that students in the control group had deficits in knowledge acquisition. For the electrical resistance question set, it appears that the changes in GMMs after instruction were quite limited.

The GMM status of the experimental group on the 'Conductors and Insulators' question set in relation to the pre- and post-test administered before and after training with CbC is shown in Table 8.

Table 8

Pre-and Post-Test GMMs of the Experimental Group

Student	Pre-Test				Post-Test							
	Conductors and Insulators		Electrical Resistance		Conductors and Insulators				Electrical Resistance			
	NSM	IMM	NSM	IMM	NSM	IMM	SDM	SM	NSM	IMM	SDM	SM
S1		✓		✓			✓			✓		
S2		✓		✓		✓				✓		
S3		✓		✓		✓					✓	
S4		✓	✓			✓				✓		
S5		✓		✓		✓				✓		
S6		✓		✓		✓			✓			
S7		✓		✓			✓				✓	
S8		✓	✓			✓				✓		
S9		✓		✓		✓				✓		
S10		✓	✓			✓					✓	
S11		✓		✓		✓				✓		
S12	✓			✓	✓					✓		
S13		✓		✓	✓						✓	
S14		✓	✓				✓					✓
S15		✓		✓				✓			✓	
S16		✓		✓			✓				✓	
S17		✓	✓				✓				✓	
S18		✓		✓		✓			✓			
S19	✓		✓			✓					✓	
S20	✓			✓		✓					✓	
S21		✓		✓	✓					✓		
S22		✓		✓		✓				✓		

S23			✓		✓		✓				✓		
S24			✓		✓		✓					✓	
S25			✓		✓	✓				✓			
S26			✓	✓				✓				✓	
S27			✓		✓		✓				✓		
T	f	3	24	7	20	4	16	6	1	3	12	11	1
	%	11,11	88,89	25,92	74,08	14,82	59,26	22,22	3,7	11,11	44,45	40,74	3,7

Table 8 shows a significant positive improvement in the GMMs of the experimental group after training in both subjects, although not at the desired level. However, it can be said that there is a clear positive change compared to the control group. The pre-test results before the training on "Conductors and Insulators" showed that 11.11% of the students were classified in the NSM and 88.89% in the IMM. Also, according to the pre-test, no student was found to be in other GMMs. However, the post-test results showed that 14.81% of the students were in the NSM, 59.26% in the IMM, 22.22% in the SDM and 3.71% in the SM.

The pre-test results on 'electrical resistance' showed that 25.93% of the experimental group were in the NSM and 74.07% were in the IMM. After the training, 11.11% of the experimental group were in the NSM, 44.44% in the IMM, 40.74% in the SDM and 3.71% in the SM. In addition, no students had the other GMMs. This means that there was a high change in the GMM of 12 students. The observed decrease in IMM and NSM, together with the increase in transitions to SM or SDM, among the students in the experimental group indicates that they were able to construct a more coherent understanding of the "Conducting Electricity" unit. This improvement supports the notion that there was a significant increase in scientific responses and a significant decrease in responses involving alternative conceptions and misconceptions. Accordingly, it can be concluded that they have more scientifically consistent and coherent knowledge of the topic and that the students in the experimental group structured the topic more effectively in their minds. This shows that the contextualized comic book experience has a facilitating effect on changing students' GMMs in a scientific way.

Up to this point the analyses have been individual. The individual matrix data can be used to create the average matrix for the class, using the means of all students, and the class GMM trend can be determined. That is, the class density matrices and class GMM trends were determined on the basis of categorization. The class density matrix for the control and experimental groups is shown in Table 9.

Table 9

The Control and Experimental Group Class GMM Density Matrices

Class	Conductors and Insulators						Electrical Resistance					
	Pre-Test			Post-Test			Pre-Test			Post-Test		
Control	0.25	0.35	0.17	0.40	0.34	0.21	0.22	0.33	0.13	0.33	0.40	0.11
	0.35	<u>0.58</u>	0.27	0.34	0.43	0.24	0.33	<u>0.62</u>	0.26	0.40	<u>0.57</u>	0.17
	0.17	0.27	0.18	0.21	0.24	0.17	0.13	0.26	0.16	0.11	0.17	0.09
Experiment	0.39	0.36	0.23	<u>0.58</u>	0.38	0.18	0.18	0.29	0.12	<u>0.57</u>	0.40	0.07
	0.36	0.42	0.23	0.38	0.32	0.12	0.29	<u>0.66</u>	0.28	0.40	0.38	0.09
	0.23	0.23	0.19	0.18	0.12	0.10	0.12	0.28	0.16	0.07	0.09	0.05

In Table 9, pre-test results for 'Conductors and Insulators', it can be seen that the control group class had mostly unscientific GMMs (since the sum of the second and third diagonal elements is about 75% of the value) and was inconsistent with its GMMs (since the diagonal elements are scattered). Similarly, the experimental group class also showed an inconsistent and mixed tendency. However, since there is no obvious dominance among the diagonal elements, it is not correct to speak of a dominant trend for the experimental group class. In the class of the control group, the value of the secondary diagonal element decreased from the pre-test (0.58) to the post-test (0.43), indicating a 15% reduction in incorrect answers as a result of the training interventions. The value of the primary diagonal element increased from pre-test (0.25) to post-test (0.40), indicating a 15% increase in scientifically correct responses. Furthermore, the value of the tertiary diagonal element decreased from pre-test (0.18) to post-test (0.17), indicating a 1% decrease in unrelated responses. In other words, the rate of unrelated (Aristotelian) responses remained almost unchanged. In the class of the experimental group, the value of the secondary diagonal element decreased from the pre-test (0.42) to the post-test (0.32), showing a 10% decrease in incorrect responses after the instructional interventions. The value of the primary diagonal element increased from pre-test (0.39) to post-test (0.58), indicating a 19% increase in scientifically correct responses. The value of the tertiary diagonal element decreased from pre-test (0.19) to post-test (0.10), indicating a 9% decrease in incorrect responses.

Moreover, in Table 9, pre-test results for 'electrical resistance', it can be understood that the control group class had mostly unscientific GMMs (since the sum of the second and third diagonal elements is approximately 78% of the value) and a mostly consistent tendency with their GMMs (since the second diagonal elements are %62). Similarly, the experimental group class also showed a mostly consistent tendency (since the second diagonal elements are %66), but had more unscientific GMMs (since the sum of the second and third diagonal elements is %82). In the control group class, the value of the secondary diagonal element decreased from pre-test (0.62) to post-test (0.57), suggesting a 15% reduction in incorrect responses due to training practice. The primary diagonal element score increased from pre-test (0.22) to post-test (0.33), reflecting an 11% increase in scientifically correct responses. The value of the tertiary diagonal element decreased from the pre-test (0.16) to the post-test (0.09), indicating a 7% decrease in unrelated responses. In the experimental group class, the value of the secondary diagonal element decreased from pre-test (0.66) to post-test (0.38), representing a 28% decrease in incorrect responses due to the instructional practices. The value of the primary diagonal element increased from the pre-test (0.18) to the post-test (0.57), indicating a 39% increase in scientifically correct answers. The value of the tertiary diagonal element decreased from pre-test (0.16) to post-test (0.05), indicating a 9% decrease in unrelated responses.

Discussion and Conclusion

The experimental and control groups had scientific, non-scientific and alternative ideas about electricity conduction before the lesson, and they were inconsistent in how they used their ideas (IMM) (see Tables 7-8). This situation shows that both groups had very little definitive knowledge before the lesson. On the other hand, after instruction, the students in the experimental group made a greater transition from IMM to the scientifically consistent model than those in the control group. In other words, the students' knowledge of electricity was more structured after the instruction with the CbC (see Table 9). On this basis, the learning environment designed for the experimental group was more useful in changing the students' GMMs than the existing learning environment used for the control group. The students with an NSM had unscientific ideas about the conduction of electricity. On the other hand, the students with IMM inconsistently chose scientific answers (correct answers), answers with alternative ideas (wrong options) and null choices. The students with SM and SDM were consistent in their knowledge and did not answer any questions with a null answer. Thus, the students with SM and SDM demonstrated strong performance in the Electric Conduction unit and had greater academic success.

The reason why the development of the GMM of the students in the experimental group was more positive than the development of the GMM of the students in the control group could be due to the teaching methods used. Teaching with the CbC in the experimental group may have given these students an advantage. The fact that the CbC was contextualized and had comic features may have led to this advantage. With the CbC, the students in the experimental group were able to structure the unit on electrical conduction in a more meaningful way in their minds. Comics can help students to gain a more solid understanding of scientific information. In particular, the use of a CbC can help students to better understand electrical conduction (Avraamidou & Osborne, 2008). Studies in the literature have shown that comics can embody scientific topics and facilitate learning (Şentürk-Çiçek, 2020). The power of electricity is an abstract topic for sixth grade students; therefore, they have difficulty learning it. It can be assumed that the CbC made the conduction of electricity a more concrete topic. In this case, the development of a GMM can lead to a significant difference in favor of the experimental group. This finding is also supported by the research of Şentürk-Çiçek (2020).

The fact that students in the experimental group showed greater improvement in their GMM after teaching with a CbC may indicate that students' interest and motivation had increased. More interest and motivation may have encouraged the students to learn the electrical conduction unit better. This may have resulted in the students in the experimental group experiencing further developments in their GMMs and showing greater performance in the electrical conduction unit. Studies in the literature support the findings of this study. Research has shown that comics increase student motivation because they teach science topics in an entertaining way (Lazzarich, 2013) and structure information more meaningfully by presenting text and visuals together (Hosler & Boomer, 2011). Therefore, the findings of the present study are consistent with the literature.

One of the reasons why the teaching practices in the experimental and control groups for the electricity unit led to differences in the development of GMMs may have been because the comics used were contextualized. As a CbC is a contextualized teaching material, it can enable students to learn more meaningfully by relating the electricity unit to their everyday lives (Glynn & Koballa, 2005). The CbC used in the present study helped students to relate the electricity unit to their everyday lives. This may have led to the differences in the development of GMMs in the experimental and control groups. Studies in the literature have shown that context-based teaching is effective in science education and that contexts should be used (Lagerström et al., 2021), and that context-based teaching materials prevent incomplete learning in science lessons and that students like them very much (Prins et al., 2018).

In the control group, the textbook may not have sufficiently linked the electricity unit to the students' everyday life. This may have caused the control group students' GMM development to be weaker than that of the experimental group. Studies in the literature support this finding. Research has shown that contextualized teaching in science education increases student success more than traditional teaching (Kuhn & Müller, 2014), that using only a textbook is insufficient in terms of content and activities in a contextualized curriculum (Overman et al., 2013), and that comics are more successful than using a booklet (Lin & Lin, 2016). Relating science subjects to daily life and using contexts in the classroom can make teaching practices more effective (Acar & Yaman, 2011). Relating science subjects to daily life can also be beneficial in achieving the goals of the curriculum (Acar & Yaman, 2011; Gilbert, 2006; Yüzbaşıoğlu, 2022).

In the experimental group, the contextualized lessons using a CbC were evaluated using the CbLST. In the control group, the lessons were carried out using the current textbook and the evaluations were also carried out using the CbLST. This may have led to differences in the development of GMMs between the two groups. Research suggests that evaluating contextualized courses using contextualized data collection tools produces more favorable results. This conclusion is supported by various studies, including those by Elmas and Eryılmaz (2015), Benckert (1997), and Overton and Potter (2011). Evaluating context-based courses with context-based data collection tools yields more positive results, and various studies support the findings of the present study (Benckert, 1997; Elmas & Eryılmaz, 2015; Overton & Potter, 2011).

Some students in the experimental group maintained IMM after the CbC lessons. One of the reasons for this may have been that the students missed some of the lessons for various reasons. The presence of students with IMM may indicate that the students had difficulty learning the topics of conductors, insulators and electrical resistance. The fact that electricity is difficult to understand may explain this situation. Studies in the literature on electrical conduction have reported consistent phenomena. Research shows that experimental and control groups have alternative conceptions before and after instructional interventions (Ayvacı et al., 2016; Günaydın, 2019). Specifically, students often hold misconceptions about electrical conduction (Canpolat & Ayyıldız, 2019; Taşdemir & Demirbaş, 2010). The findings of this study are consistent with broader research on misconceptions (e.g., Ezberci-Çevik, 2018; Yaz, 2022; Yüzbaşıoğlu, 2022) across different scientific domains.

The fact that students in both the experimental and control groups continued to have NSMs and IMMs after instruction, showed that students structured the topic of electricity in their minds in a non-scientific way. It has been noted that electricity is difficult for students to understand (Mırçık, 2018). For this reason, research has been conducted on how best to teach electricity at almost all educational levels. Students display incomplete learning and alternative ideas about electricity and may have difficulty understanding concepts related to electricity (Ateş & Polat, 2005; Çıldır & Şen, 2006). Students show incomplete learning and alternative ideas at almost all levels of education (Ateş & Polat, 2005; Çıldır & Şen, 2006; Görecek-Baybars, 2018; Hussain et al., 2013; Karal et al., 2009). The fact that students generally have problems structuring the topic of electricity in their minds may explain why students in the present study continued to have NSMs and IMMs after the teaching practices.

Class GMM density matrices were revealed in the individual GMM vectors, from which the GMM trends of the classes were revealed. The GMMs of the experimental and control groups tended to be IMMs before and after instruction. Both groups had both scientific and alternative ideas about the conduction of electricity. Students may be inconsistent in using the information they have (Kurnaz, 2012, 2018, 2019, 2022; Ezberci-Çevik, 2018; Vadnere & Joshi, 2009; Yaz, 2022; Yüzbaşıoğlu, 2022). The fact that the rate of IMM in the experimental group was lower than that in the control group can show that teaching with a CbC is more effective in developing a GMM than teaching in textbook-based lessons.

The GMMs of the students in the experimental and control groups were similar in that they were mostly IMMs before the instruction, and it was concluded that the students entered the learning environment primarily with IMMs. When the changes in GMM were compared after the teaching sessions, there was more progress in the experimental group of students and it was concluded that the designed learning environment was more successful. It was concluded that teaching with a CbC was more effective in developing GMMs for conducting electricity units.

For the question group on conductors, insulators and electrical resistance, the GMM tendencies of the control and experimental group students before and after instruction were in an inconsistent mixed trend state (inconsistent hash). However, the experimental group showed a relatively high rate of development and tended to have IMMs.

Implications

Based on the results, the following recommendations are made:

1. Teaching through a CbC facilitates learning, attracts students' attention to the lesson and relates the information learnt to everyday life. CbCs could be developed and used as course materials in learning environments for topics that students have negative attitudes towards and find boring or abstract.

2. To deliver the electricity unit, CbCs can be used as teaching materials and a CbLST can be used as a data collection tool.

GMMs can be identified with multiple choice tests prepared for this purpose.

Statement of Responsibility

All the authors have sufficiently contributed to the study and agreed with the results and conclusions.

Conflicts of Interest

There are no competing interests in this study. The authors declare that they have made equal contributions to the article.

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