Application of analogy method in teaching electromagnetic field and electromagnetic wave theory

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Abstract: Firstly, this paper puts forward an effective analogy teaching method for electromagnetic field and electromagnetic wave theory on the basis of analyzing the teaching characteristics of this course. Then, several aspects of analogy teaching method can be applied in this course are discussed. Finally, the analogy of boundary conditions is taken as an example to illustrate how to use analogy method in practice teaching. It also summarizes several problems that need to be paid attention to when using analogy method in teaching.

1. Introduction
Analogy method is a way of thinking to know things. According to the similarity in some aspects between two objects, it is inferred that they may be the same or similar in other aspects. Analogy method is a very important method of scientific cognition. Using this method, learners can successfully realize the transfer of knowledge, easier to deduce new knowledge from the original knowledge. Analogy method makes it much easier for learners to learn new knowledge. Therefore, this method is more effective than other methods in teaching difficult content.

Electromagnetic field and electromagnetic wave theory is an important basic course for electronic and electrical majors such as communication engineering and electronic information engineering. On one hand, the research objects of the course are invisible fields and waves, so the concepts are abstract and difficult to understand. On the other hand, a large number of mathematical field theory operations are involved in the course of learning. So electromagnetic field and electromagnetic wave theory has always been a difficult course for students to learn and teachers to teach.

Electromagnetic field and electromagnetic wave theory course has many similarities with other courses in knowledge and content. There are also many similarities between its sections. Such a course is a typical course that applies analogy teaching method.

2. Three Aspects of Analogy Teaching Method Can Be Used in Electromagnetic Field and Electromagnetic Wave Theory Course.

2.1 Analogizing with Other Relevant Courses Content

2.1.1 Analogizing with The General Physics of Electromagnetism course
The course of electromagnetic field and electromagnetic wave theory is based on electromagnetism of general physics. Although the specific key points and knowledge points are different, the content system composition of the two courses are the same. Both of the two courses are based on Maxwell's equations as the core content, so that there are here are many aspects that can be used by analogy method. I have listed only a few analogies of the discipline in table 1.
Table 1 Analogies between electromagnetic fields in electromagnetic fields and electromagnetic wave theory course and electromagnetic field in general physics course

|                                                                 | Electromagnetic fields in electromagnetic fields and electromagnetic wave theory | Electromagnetic fields in general physics |
|-----------------------------------------------------------------|-----------------------------------------------------------------------|----------------------------------------|
| Gauss's law for electric fields                                  | \[ \iiint \mathbf{D} \cdot d\mathbf{s} = \iiint \rho \cdot d\mathbf{V} \] | \[ \oint \mathbf{D} \cdot d\mathbf{s} = \sum_{i=1}^{n} q_i \] |
| Circuit law for electric fields                                 | \[ \oint \mathbf{E} \cdot d\mathbf{l} = -\int \mathbf{\frac{\partial \mathbf{B}}{\partial t}} \cdot d\mathbf{s} \] | \[ \oint \mathbf{E} \cdot d\mathbf{l} = 0 \] |
| Gauss's law for magnetic field                                  | \[ \iiint \mathbf{B} \cdot d\mathbf{s} = 0 \] | \[ \iiint \mathbf{B} \cdot d\mathbf{s} = 0 \] |
| Circuit law for magnetic field                                 | \[ \oint \mathbf{H} \cdot d\mathbf{l} = -\int \left( \mathbf{J} + \mathbf{\frac{\partial \mathbf{D}}{\partial t}} \right) \cdot d\mathbf{s} \] | \[ \oint \mathbf{H} \cdot d\mathbf{l} = \sum_{i=1}^{n} I_i \] |

As can be seen from table 1, the content structure of electromagnetic field and electromagnetic wave theory course is the same as the content structure of general physical electromagnetics course, which studies the properties of electric field and magnetic field through gauss theorem and circuitual theorem. If such analogies are given to students before teaching this part of the content, it will help them to grasp the context system of the content from a macro perspective. In addition, during the teaching of each discipline, students should review the corresponding content of ordinary physics before learning new knowledge, which is helpful for students to accept new knowledge. It is also helpful to distinguish the differences of the same discipline between the two courses. One applies to all electromagnetic fields, and one only applies to static electromagnetic fields.

2.1.2 Analogizing with Circuit Analysis course
Many laws in electromagnetic field and electromagnetic wave theory course and circuit analysis course also have analogies. For example, the constitutive relation \( \mathbf{J} = \sigma \mathbf{E} \) of conductive medium in constant electric field is similar to ohm's law \( \mathbf{U} = \mathbf{IR} \) in circuit course. And ohm's law can be deduced from the constitutive relation.

\[
\mathbf{U} = -\int \mathbf{E} \cdot d\mathbf{l} = -\int \mathbf{\frac{\mathbf{J}}{\sigma}} \cdot d\mathbf{l} = -\rho \int \mathbf{\frac{I}{S}} \cdot d\mathbf{l} = \rho \int \mathbf{\frac{I}{L}} = \mathbf{IR}
\] (1)

It can be seen that the constitutive relation of conductive medium in constant electric field is ohm's law in differential form.

Another example is that the expression of complex vector of physical quantity in time-varying electromagnetic field is similar to that of phasor in circuit course. They were all introduced to make complex operations easier. And the introduction of such expressions requires conversion between different expressions.

2.2 Analogies of The Framework of Different Chapters
Static field (electrostatic field, constant magnetic field, constant electric field) is basically developed in accordance with the same logic. And the frame system has a strong analogy. These chapters begin with the analysis of the basic equations of the corresponding field to obtain the nature of the field and the boundary conditions. And both end with discussing the solution of the magnitude of the main circuit components in the corresponding field and analyzing the energy expression of the field. Table 2 only lists several basic field equations and the analogical relations of corresponding field properties.
Table 2 Analogies between three basic equations and properties of static fields

| Condition | Gauss's law | Circuit law |
|-----------|-------------|-------------|
| Electrostatic field in vacuum (excited by static charge) | \[ \oint_S D \cdot ds = \iiint_V \rho_dV \] \[ \nabla \cdot \mathbf{D} = \rho_v \] (divergent field) | \[ \oint_L E \cdot dl = 0 \] (irrotational field) |
| Constant magnetic field in a vacuum (excited by constant current) | \[ \oint_S B \cdot ds = 0 \] \[ \nabla \cdot \mathbf{B} = 0 \] (nondivergent field) | \[ \oint_L H \cdot dl = \int_S \mathbf{J} \cdot ds \] \[ \nabla \times \mathbf{H} = \mathbf{J} \] (curl field) |
| Constant electric field in conductive medium (excited by constant current) | \[ \oint_S J \cdot ds = 0 \] \[ \nabla \cdot \mathbf{J} = 0 \] (nondivergent field) | \[ \oint_L E \cdot dl = 0 \] \[ \nabla \times \mathbf{E} = 0 \] (curl field) |

With this analogy, teachers can lead students to review the relevant content and analysis ideas of electrostatic field when teaching the content of constant magnetic field and constant electric field. Using the same frame system, the students are guided to think about the analysis train of thought and deductive direction. It is helpful for students to grasp the whole chapter of knowledge from the macro context.

2.3 Analogies of Physical Quantities and Their Establishment Processes

Throughout the course of electromagnetic field and electromagnetic wave theory, analogies between different physical quantities are everywhere. For example, the analogy between the strength of an electric field and the strength of a magnetic field. Another example is the analogy between the electric displacement vector and the magnetic induction intensity. There are also analogies of capacitance, inductance, conductance, etc. The physical meaning of these physical quantities is similar, the definition form is the same, the solution method of the quantity value is the same. By using analogy teaching method, students can draw inferences about other cases from one instance to get result with half effort. Table 3 shows the analogies of capacitance, inductance and resistance.

Table 3 Analogy of capacitance, inductance and resistance

| Section                     | Capacitance | Inductance | Resistance |
|-----------------------------|-------------|------------|------------|
| Electrostatic field         | \[ C = Q/U \] | \[ L = \Phi_m/I \] | \[ G = I/U \] |
| Constant magnetic field     | To describe how strong or weak a conductor can hold charge. | To describe the circuit's ability to generate self-induction. | To describe the conductivity of a conductor |
| Physical significance       | definition  | definition  | definition  |
| Influence factor            | It is only related to the shape, size and material of the conductor, and has nothing to do with whether the conductor has charge or not. | It is only related to the shape, size and material of the circuit, and has nothing to do with whether the circuit has current or not. | It is only related to the shape, size and material of the conductor, but has nothing to do with whether the conductor has current or not. |
| Solution                    | Set \( Q \) to solve for \( U \), and then divide them | Set \( I \) to solve for \( \Phi_m \), and then divide them | Set \( I \) to solve for \( U \), and then divide them |
3. Problems Needing Attention and Examples of Application of Analogy Teaching Method

3.1 Problems to Be Paid Attention To When Applying Analogy Teaching Method
The characteristics of the teaching content of electromagnetic field and electromagnetic wave theory determine that the most common and best teaching method is analogy method. However, in order to achieve the expected teaching effect, it is necessary to deeply analyze the teaching content. Make the analogy method and teaching content organic combination. There are several issues that need to be paid attention to when using analogy teaching method.

3.1.1 No blind analogy, no cookie-cutter
The two analogies must be comparable. Do not use far-fetched analogies, otherwise it may lead to wrong conclusions. Analogies are a good teaching method for this course, but not always and everywhere. Therefore, one teaching method cannot be applied mechanically from beginning to end, which is against the law of scientific cognition. In addition, even if it is suitable to use the method of analogy, it cannot be used entirely. Because cookie-cutter teaching methods will make students feel boring and boring. Therefore, teachers need to carefully analyze the teaching content, select typical content, choose the right time to use this method. Remember to avoid blind analogy.

3.1.2 Do Macro Planning and Make Excellent Teaching Design
The relevant content that can be used for analogy may appear in the same lecture, but it is more likely to appear in different lectures, with a long time between them. In order to use analogies more effectively, teachers need to make macro planning before the course starts. When analogical content first appears, it should be well prepared for analogies. For example, mention analogies to be covered in the future. When the analogical content appears for the second time, it is necessary to review the previous content to arouse students' memories, inspire their thinking and realize knowledge transfer. Only by means of a complete closed-loop learning, can the learning efficiency and teaching quality be effectively improved. However, such a closed-loop learning situation needs the macro planning and teaching design of teachers, which cannot be achieved by improvisation.

3.1.3 Be Comprehensive
There are strong similarities between the analogies. But it is different content after all, there must be differences. Similarity analogy can realize knowledge transfer and reduce learning difficulty. The discrimination and analysis of the differences are more conducive to deepening the understanding of the two aspects. Therefore, teachers should make a comprehensive comparison in the relevant content analogy, summarize the same and distinguish the differences.

3.2 Examples of Application of Analogy Teaching Method
Taking the boundary conditions of electric field and magnetic field as an example, the following illustrates how to do teaching design when applying analogy method.

The variation law of field components on the interface of different media is called boundary condition. Both electrostatic field and constant magnetic field have boundary conditions. The boundary conditions include normal boundary condition and tangential boundary condition. In these analogies, the boundary conditions of electrostatic field are first contacted, and then the boundary conditions of constant electric field are contacted. The two parts of the analogies belong to the chapters of electrostatic field and constant magnetic field respectively. The teaching design is completed in the following steps.

(1) Analysis and derivation of boundary conditions of electrostatic field.
First, make a cylindrical closed surface with the top and bottom surface on both sides of the interface and parallel to the interface, as shown in figure 1. The boundary condition of normal component is deduced, according to gauss theorem of electrostatic field. And then the discontinuity of the normal component of electric displacement vector in electrostatic field is obtained, according to
the normal boundary conditions. After that, make a rectangular loop with two long sides on both sides of the interface and parallel to the interface, as shown in figure 2. Based on the circuital theorem of electrostatic field, the boundary conditions of tangential components are derived, finally.

![Figure 1 Derivation of normal boundary condition of electrostatic field](image1)

![Figure 2 Derivation of tangential boundary condition of electrostatic field](image2)

(2) After the knowledge points are obtained, lead the students to review and summarize the derivation ideas of this process and give a clear process block diagram, as shown in figure 3. And tell students that figure 1, figure 2 and this derivation in figure 3 will be used again in the next chapter. This will leave the stage for the next chapter on the analysis of the constant field boundary conditions.

![Figure 3 process block diagram of electrostatic field boundary condition derivation](image3)

(3) Analysis and derivation of boundary conditions of constant magnetic field.

Before learning the problem of constant magnetic field boundary conditions, review the process block diagram of electrostatic field boundary conditions in figure 3. And guide the students to transfer the knowledge, get the constant magnetic field boundary condition should also use the same method and the same process derivation. Then analyze the differences and similarities between the basic equations of electrostatic field and constant magnetic field. Select the correct basic equation of the constant magnetic field to replace the basic equation of the electrostatic field in figure 3. Finally, according to gauss theorem \( \int_B B \cdot ds = 0 \) and circuitual theorem \( \int_H H \cdot dl = I \) of constant magnetic field, derive the normal boundary conditions and tangential boundary conditions of constant magnetic field respectively. The differences and similarities between the boundary conditions of constant magnetic field and electrostatic field are obtained through comparison (the normal component of constant magnetic field magnetic induction intensity is continuous, and the tangential component of magnetic field intensity is discontinuous).

The chapter of constant electric field in electromagnetic fields and electromagnetic wave theory course also has boundary condition problem. By analogy, this idea is used twice in electrostatic fields and constant magnetic fields and fully discussed. Students are already familiar with the boundary...
condition problem when they encounter it for the third time in constant electric field. Students basically can find ideas to analyze and derive the correct results, without teachers' inspiration. Moreover, students don't feel the difficulty of learning because they feel that everything comes naturally.

4. Conclusion
Analogy method is a very important teaching method of electromagnetic field and electromagnetic wave theory course. This teaching method can not only teach students knowledge efficiently, but also train students' thinking. The way of presenting research questions to students is recognized and welcomed by students. Practice has proved that this teaching method has received very good teaching effect.

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