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TEAM-BASED LEARNING FOR DEVELOPING COMMUNICATIVE COMPETENCE IN AN UNDERGRADUATE ELECTROMAGNETISM COURSE: A METHODOLOGICAL FRAMEWORK

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Abstract: Electromagnetism is among the most conceptually demanding parts of the introductory university physics sequence, and it is also a field in which scientific communication (explaining invisible fields, justifying symmetry arguments, defending a solution to peers) is central to professional practice. Conventional lecture-and-problem-set instruction rarely develops these communicative skills systematically. This article proposes a methodological framework for teaching the Electromagnetism section of General Physics through Team-Based Learning (TBL) combined with peer instruction, case studies, jointly written laboratory reports and structured scientific debate. The framework operationalises communicative competence as five observable components (scientific language, argumentation, listening and questioning, collaboration, and scientific presentation), links each component to specific classroom activities, and provides a seven-module sequence from Coulomb's law to Maxwell's equations, together with an assessment rubric and a monitoring design based on concept inventories and the normalised gain. The paper is a design-oriented contribution grounded in the published evidence on active learning; empirical results of a pedagogical experiment are outside its scope and a protocol for such a study is provided.

Keywords: team-based learning; communicative competence; electromagnetism; physics education; peer instruction; active learning; higher education

1. Introduction

Graduates of physics and engineering programmes are expected to do more than manipulate formulae. They must explain physical models to colleagues and non-specialists, collaborate in teams, and justify design decisions with evidence. Within the university physics sequence, electromagnetism is a particularly suitable setting for developing these abilities. Its central objects (fields, flux, circulation, potential) cannot be seen, its mathematics is vectorial, and its conceptual difficulties are well documented (Maloney et al., 2001; Ding et al., 2006). Such difficulties are typically exposed and repaired when students must articulate their reasoning to one another.

A substantial body of research indicates that interactive-engagement methods improve conceptual understanding in physics. In a survey of data from more than six thousand students, Hake (1998) reported markedly higher normalised gains in interactive-engagement courses than in traditional ones, and a meta-analysis of 225 studies in science, technology, engineering and

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mathematics found higher examination scores and lower failure rates under active learning (Freeman et al., 2014). However, most of this literature measures conceptual learning; the development of communicative competence as an explicit, assessed learning outcome in electromagnetism courses has received far less systematic attention.

This article addresses that gap. Its aim is to present a methodological framework in which the Electromagnetism section of an undergraduate General Physics course is taught through Team-Based Learning (TBL) and related collaborative methods so that conceptual learning and communicative competence develop together. The paper (i) defines communicative competence for this context in measurable terms, (ii) adapts the TBL cycle to electromagnetism modules, (iii) illustrates the approach with worked module materials, and (iv) specifies an assessment and monitoring design.

2. Theoretical Background

2.1 Communicative competence in physics education

The notion of communicative competence originates in applied linguistics, where Canale and Swain (1980) distinguished grammatical, sociolinguistic and strategic components. In professional education it is understood more broadly as the ability to receive, process, transmit and justify information in a given disciplinary setting. In physics, the disciplinary language comprises terminology, mathematical expressions, diagrams, graphs and experimental data; competence therefore includes the coordinated use of these representations (Redish, 2003).

2.2 Social constructivism and cooperative learning

The framework rests on Vygotsky's (1978) view that higher mental functions develop first in social interaction. A student who cannot yet resolve a problem alone may do so with peers within the zone of proximal development, and the effort of explaining consolidates understanding. Johnson, Johnson and Smith (2014) identify five elements of effective cooperative learning: positive interdependence, face-to-face promotive interaction, individual accountability, social skills and group processing. Springer, Stanne and Donovan (1999) found in a meta-analysis that small-group learning in science, mathematics, engineering and technology had positive effects on achievement, persistence and attitudes.

2.3 Team-based learning and peer instruction

TBL organises a course around permanent teams and a repeated cycle of preparation, readiness assurance and application (Michaelsen, Knight & Fink, 2004; Michaelsen & Sweet, 2008). Its distinguishing feature is the readiness assurance process: an individual test followed by the same test taken by the team, with immediate feedback, which creates accountability and generates discussion of precisely those concepts students find difficult. Peer instruction (Crouch & Mazur, 2001) similarly uses conceptual questions answered individually, then discussed with a neighbour and answered again. Cooperative problem solving with assigned roles was developed for introductory physics by Heller and colleagues (Heller, Keith & Anderson, 1992; Heller & Hollabaugh, 1992), and problem-based learning has been reviewed by Hmelo-Silver (2004). Together, these approaches provide a repertoire of structured peer communication that can be combined in a single course design.

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3. The Methodological Framework

3.1 Operational definition of communicative competence

For the purposes of the framework, communicative competence in an electromagnetism course is defined by five components, each tied to observable behaviours (Table 1).

Table 1. Components of communicative competence and observable indicators

Component	Observable indicator (example)	Principal activity
Scientific language	Distinguishes field strength from potential; states units	iRAT/gRAT, written appeals
Argumentation	Justifies the choice of a Gaussian surface by symmetry	Application tasks, debate
Listening and questioning	Asks a clarifying question; restates a peer's argument	Peer instruction, laboratory defence
Collaboration	Fulfils a team role; resolves disagreement with evidence	Team roles, peer evaluation
Scientific presentation	Combines sketch, formula and verbal reasoning within a time limit	Simultaneous reporting, laboratory defence

3.2 The TBL cycle adapted to electromagnetism

The course is divided into seven modules of about two weeks each: (1) electrostatic field and Coulomb's law; (2) Gauss's theorem; (3) potential, capacitance and field energy; (4) direct current; (5) magnetic field and current; (6) electromagnetic induction; (7) Maxwell's equations and electromagnetic waves. Teams of five to seven students are formed by the instructor and remain constant. Each module follows the sequence in Table 2.

Table 2. The module cycle

Stage	Content	Communicative focus
Preparation	Textbook sections, short video, simulation; focus questions	Terminology
Individual readiness test (iRAT)	10–12 conceptual multiple-choice items	Individual accountability
Team readiness test (gRAT)	Same items answered by consensus with immediate feedback	Discussion and justification
Written appeal	Evidence-based challenge of an item	Written argumentation

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Stage	Content	Communicative focus
Mini-lecture	Instructor addresses the most frequent errors	—
Application	Complex team problem or case; all teams work on the same task	All five components
Simultaneous report	Teams display solutions at the same moment; differences are debated	Presentation, critique
Peer evaluation	Rubric-based rating of each member's contribution	Reflection

Team roles rotate in every session: a coordinator who manages time and turn-taking, a calculator who records the logic of the solution and checks units, a visualiser who draws field lines and vector diagrams, a sceptic who tests assumptions and limiting cases, and a reporter who presents the result. The sceptic role is intended to institutionalise the questioning component, since students rarely challenge one another unprompted.

3.3 Illustrative module materials

Module 2 (Gauss's theorem). A readiness-test item asks: “A charge Q is at the centre of a cube. What is the flux through one face?” The correct answer, $Q/(6\varepsilon_0)$, follows from the total flux Q/ε_0 and the symmetry of the cube. The application task asks each team to find the electric field of a sphere of radius R carrying a uniform volume charge density ρ, inside and outside the sphere, and to compare it with that of a conducting sphere of the same total charge. Using a concentric spherical Gaussian surface, the field inside is $E(r) = \rho r/(3\varepsilon_0)$ and outside $E(r) = \rho R^3/(3\varepsilon_0 r^2) = Q/(4\pi\varepsilon_0 r^2)$; the two expressions agree at $r = R$. In a conductor the field inside vanishes and the excess charge resides on the surface. The communicative demand lies in justifying, in words and a sketch, why the spherical surface is appropriate and why the two cases differ. A linked case study considers why occupants of a metal-bodied vehicle are protected from lightning, which leads students to the vanishing of the static field within a conductor.

Module 6 (Electromagnetic induction). A coil of $N = 100$ turns and area 20 cm² lies in a magnetic field of 0.5 T parallel to its axis; the field is reduced uniformly to zero in 0.1 s. Students compute the induced emf, $\varepsilon = N\Delta\Phi/\Delta t = 1$ V, and, for a coil resistance of 2 Ω, the charge passed, $q = \Delta\Psi/R = 0.05$ C, and explain why the charge does not depend on the duration of the change. A structured debate then tests the proposition that Lens's law is a consequence of energy conservation, with students required to reason about what would happen if the induced current reinforced the change in flux.

Module 7 (Electromagnetic waves). The case study asks teams to evaluate publicly circulating claims about the hazards of wireless radiation. A 2.4 GHz photon has energy $hf \approx 1.6 \times 10^{-24}$ J (about 10 μeV), roughly a million times smaller than typical atomic ionisation energies (about 10 eV), so such radiation is non-ionising; teams then prepare a 90-second explanation for a lay audience. The task trains communication across levels of expertise, an aspect of competence that is seldom assessed.

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3.4 Laboratory work as team report and defence

Laboratory sessions (for example, capacitor characteristics, the dependence of source power on load, the magnetic field of a solenoid, induced emf, RLC resonance) are carried out by teams, who agree a measurement plan, keep a joint log and submit one report containing hypothesis, theory, set-up, data with uncertainties, analysis and reflection. At the defence, the presenter is chosen at random by the instructor and members of other teams ask at least two questions; a proportion of the team mark depends on individual answers. This procedure maintains individual accountability, one of the five elements identified by Johnson et al. (2014).

3.5 Structured scientific debate

Debates are framed as evidence-based discussions of interpretation, not contests. After preparation, teams argue an assigned position, answer questions, rebut, and then exchange sides. The aim is practice in argumentation and in revising a position in light of evidence. Debate topics are drawn from conceptual difficulties documented in the literature (Maloney et al., 2001; Ding et al., 2006), for instance whether zero potential implies zero field.

3.6 Assessment of communicative competence

Because communicative competence cannot be captured by a test alone, assessment draws on several sources: instructor observation, peer evaluation, self-assessment, team products and conceptual tests. Table 3 gives a four-level rubric aligned with Table 1.

Table 3. Rubric for communicative competence (levels 4 to 1)

Criterion	4 (Excellent)	3 (Good)	2 (Satisfactory)	1 (Unsatisfactory)
Scientific language	Terms and units consistently correct	Minor imprecision	Frequent confusion	Misuses terms
Argumentation	Fully justified by laws or calculation	Justified with gaps	States results only	No justification
Listening and questioning	Clarifying questions; accurate restatement	Asks questions, sometimes superficial	Rarely asks	Does not listen
Collaboration	Fulfils role and supports others	Fulfils role	Partially fulfils role	Does not participate
Presentation	Sketch, formula and speech coherent	Coherent, minor flaws	Disorganised	Unclear

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4. Evaluation Design

The framework is intended to be tested empirically. A quasi-experimental design is proposed with an experimental group taught by the framework and a control group taught by conventional lecture and problem sessions, matched on prior attainment and taught the same content over the same period. Conceptual understanding is measured before and after instruction by a validated inventory such as the Conceptual Survey of Electricity and Magnetism (Maloney et al., 2001) or the Brief Electricity and Magnetism Assessment (Ding et al., 2006). The normalised gain is computed as

$$g = (\text{post}\% - \text{pre}\%) / (100\% - \text{pre}\%),$$

following Hake (1998). Communicative competence is measured by the rubric in Table 3 applied by two independent raters (with inter-rater agreement reported), by a self-assessment questionnaire administered at the start and end of the course, and by peer ratings. Group differences are tested with Student's t-test or, where assumptions are not met, the Mann–Whitney test, and effect sizes are reported. Ethical approval and informed consent are obtained before data collection, and participants' data are anonymised.

5. Discussion

The framework is designed around a deliberate alignment between content and communicative demand: the activities that research has shown to promote conceptual change (peer discussion, team problem solving, immediate feedback) are the same activities through which communicative competence is exercised. Because teams are permanent and testing is both individual and collective, each student is repeatedly required to explain and to be explained to, and TBL's readiness assurance supplies natural, recurring occasions for argumentation and appeal. The use of real-world cases (grounding, magnetic resonance imaging safety, wireless charging, public communication about radiation) connects the physics to professional contexts in which engineers and teachers must communicate with non-specialists.

Several limitations should be noted. First, the evidence cited for the effectiveness of active learning concerns mainly conceptual and examination outcomes; whether the same approaches improve communicative competence to a measurable degree in electromagnetism is the hypothesis of the proposed study, not an established result. Second, TBL requires instructor preparation of high-quality test items and application problems, and its success depends on team formation and on students completing the preparation stage. Third, rubric-based assessment of communication involves rater subjectivity, which calls for rater training and reporting of agreement. Finally, the framework was conceived for a particular curriculum in a Central Asian higher-education context; adaptation will be needed for other class sizes, languages and resources.

6. Conclusion

This article has presented a framework for teaching the Electromagnetism section of General Physics by Team-Based Learning and related interactive methods with the explicit aim of developing communicative competence alongside conceptual understanding. The contribution consists of an operational definition of the competence, an adaptation of the TBL cycle to seven electromagnetism

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modules, illustrative module materials, a laboratory report-and-defence procedure, a debate format, an assessment rubric and an evaluation protocol. Future work will report the results of a controlled pedagogical experiment based on the protocol described in Section 4.

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