Article

Integrating Project-Based and Community Learning for Cross-Disciplinary Competency Development in Nutrient Recovery

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Supplementary Material

Section S1. Brief technical report on zeolite-based adsorbent preparation and field application

1.1. Zeolite preparation and modification

Natural zeolite was donated by Zeonatec (Guayaquil, Ecuador). After washing and drying, 7 kg of material were milled and sieved to obtain both powdered (mesh 200) and granular (mesh 35) fractions. A total of 1500 g of each was modified via ion exchange using 0.1 M solutions of $FeCl_3$, $MnCl_2$, and $ZnCl_2$ under neutral pH, with agitation for 3 hours. Materials were washed, dried, and stored for characterization and application.



Figure S1. Students performing the pre-treatment of natural zeolite.



Figure S2. Students obtaining the modified zeolite.

1.2. Characterization of zeolite materials

X-ray Diffraction (XRD): analysis using a Bruker D8 Advance Eco diffractometer revealed mineral phases. Natural zeolite consisted of quartz, mordenite, clinoptilolite-Na, laumontite, and montmorillonite. The modified zeolite contained higher quartz content with remaining zeolitic phases reduced, suggesting partial phase transformation or dissolution during modification.

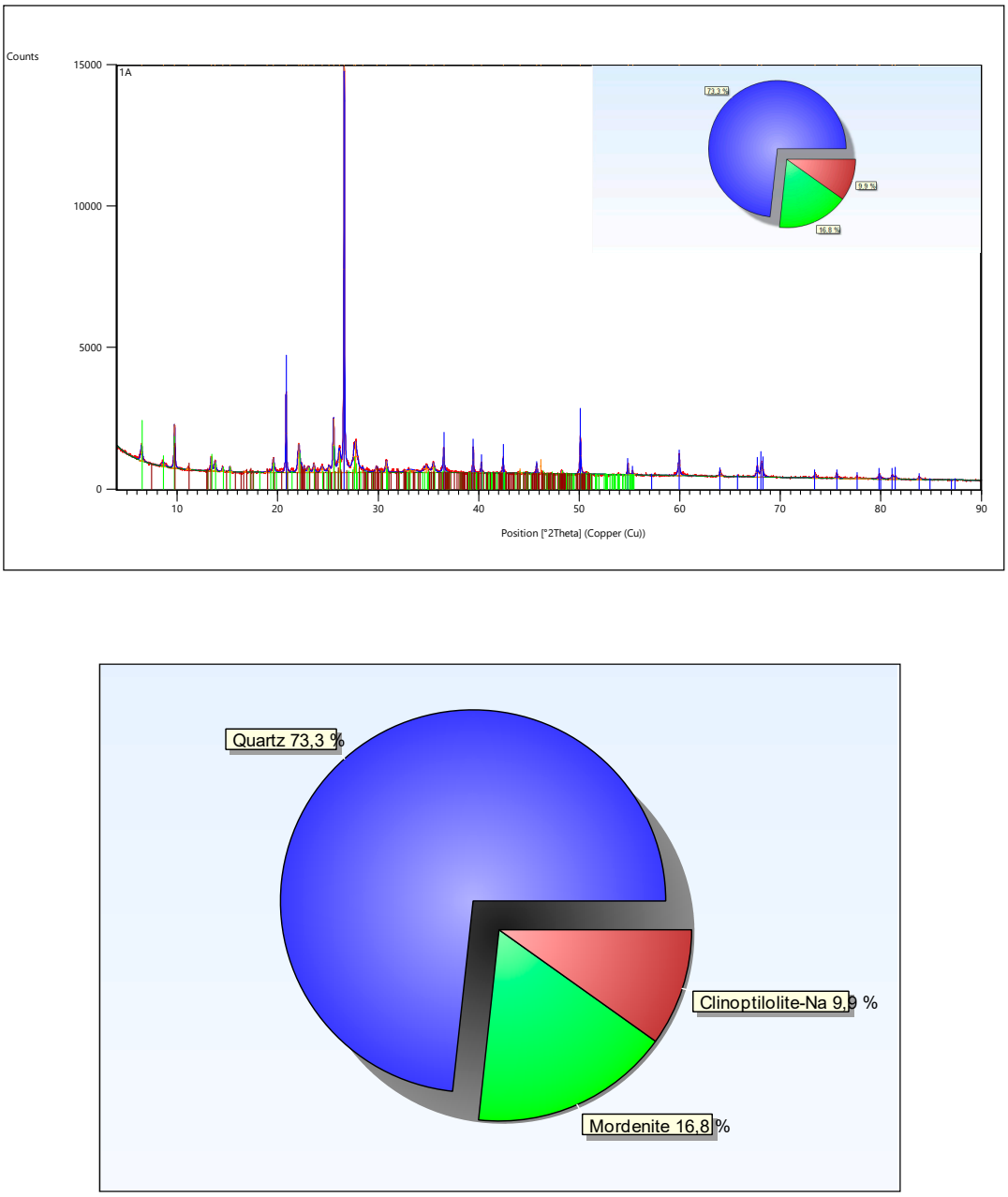

Figure S3. Students processing XDR data of the modified zeolite.

X-ray Fluorescence (XRF): chemical composition analysis (Bruker S1 Turbo SDR) showed that the modified zeolite had increased Fe_2O_3 (3.36%), MnO (1.01%), ZnO (7.27%), and K_2O (2.53%) compared to natural zeolite.

Specific Surface Area (SSA): using a Chemisorb 2720 system (N_2/He gas mixture), the SSA increased from 65.56 m^2/g (natural) to 136.17 m^2/g (modified), indicating enhanced adsorption capacity.



Figure S4. Students performing physicochemical characterization of modified zeolite

1.3. Adsorption and nutrient removal tests

Wastewater effluent was treated with modified zeolite using 1500 g of material and immersed in 70 L of the nutrient solution for 4 hours. Zeolites were then washed, dried, and packaged for field trials conducted by undergraduate Agricultural Engineering students. Wastewater samples were analyzed: raw effluent, effluent after contact with granular zeolite, and after contact with powdered zeolite. Nutrient removal rates varied (Table S1):

Table S1. Nutrient removal efficiencies comparison between granulated and powdered modified zeolites.

	Nutrient removal % using granulated zeolite	Nutrient removal % using powdered zeolite
Ammoniacal nitrogen	39.2	37.2
Ammonia	71.1	70.6
Amonium	72.3	72.3
Phosphates	23.3	40.2
Nitrites	45.3	66.0
Total phosphorus	30.5	49.2
Total nitrogen	11.1	25.0

These results confirm the potential of modified zeolites for nutrient recovery and their feasibility for slow-release fertilizer applications.



Figure S5. Students performing adsorption activities with modified zeolite and real urban wastewater.

1.4. Nutrient release and bioavailability

Modified zeolites enriched with nutrients were tested for phosphate and ammonium release under controlled soil and aqueous conditions. Granular zeolite mixed with soil released higher phosphate levels (up to 2.15 mg/L) than powdered forms. Ammonium release remained constant (\~0.03 mg/L), indicating selective nutrient retention and controlled release behavior.

1.5. Field Application and soil sampling

Collaborations with local families were established. Baseline soil sampling and fertility analysis were conducted (INIAP and UTPL laboratories). Three treatments were applied in five farms: (a) control, (b) zeolite only, and (c) zeolite

+ fertilizer. Plant growth and soil fertility indicators were monitored, including leaf count, plant height, fruit size, and pasture biomass.



Figure S6. Students performing soil sampling activities.



Figure S7. Students establishing plots for zeolite application.



Figure S8. Students working on laboratory activities and field data collection.

1.6. Community engagement and knowledge transfer

Workshops titled "The Effect of Zeolite and Fertilizers on Soil and Crop Productivity" were conducted. Each participating family received personalized training and a fertilization kit. Attendance records, photographs, and beneficiary signatures were collected to document participation. Community feedback indicated strong interest in future application of the zeolite-based fertilizer.



Figure S9. Workshop held in the community.



Figure S10. Educational materials prepared by students to present the project to the community during the outreach workshop.

Section S2. Survey instrument validation

To validate the content of the survey, there were consulted some experts in the field to ensure that the survey accurately measures the intended constructs. The questions were as follows:

1. What was the greatest challenge you faced during the project implementation in San Cayetano?
   Limited technical resources
   Lack of community support
   Insufficient financial resources
   Conflicts with farmers

2. Which skill did you develop the most during the project?
   Community communication
   Scientific research
   Teamwork
   Agricultural field techniques
3. What was the main benefit of the project for students?
   Practical application of knowledge
   Development of social skills
   Improvement of technical competencies
   Networking opportunities
4. What would you recommend to improve future community-based projects with students?
   More financial resources
   Greater community involvement
   Better planning and time management
   Increased student participation in initial planning
5. Would you suggest including additional community-linkage projects in academic activities?
   Yes
   No

The validation process was conducted according to the following framework:

2.1. Expert selection

A panel of 17 experts was selected based on their strong knowledge of the survey topic and research methodology.

2.2. Material delivery

The experts were provided with the following materials:

- The objectives of the survey
- Operational definitions of each construct
- The complete questionnaire
- An evaluation matrix to assess each item according to the following criteria:
  - **Clarity:** Is the item clearly and easily understood?
  - **Relevance:** Does the item effectively contribute to measuring the intended construct?
  - **Ambiguity:** Could the item be interpreted in multiple ways?

- **Adequacy**: Are there a sufficient number of items to comprehensively cover each construct?

2.3. Analysis of expert feedback

- The Content Validity Coefficient (CVC) was calculated for each item.
- Experts® qualitative feedback and suggestions were reviewed and discussed.
- Modifications were made to the items and the overall structure of the questionnaire based on expert consensus.

2.4. Pilot testing (pre-test)

A pilot test was conducted to identify potential issues related to clarity, formatting, and length prior to full deployment.

2.4.1. Pilot sample selection

A small group of 10 students was selected for the pilot test.

2.4.2. Survey administration

The questionnaire was administered under conditions as similar as possible to the final implementation.

2.4.3. Feedback collection

After completing the survey, students were asked to provide feedback on:

- Clarity of instructions and questions
- Question difficulty
- Survey length
- Logical flow and coherence
- Any confusion or ambiguity
- Time required to complete the survey

2.4.4. Analysis and Revisions

- Qualitative feedback from the pilot test was analyzed.
- Problematic questions (e.g., unclear wording, ambiguous answer choices, formatting issues) were identified.

- Necessary adjustments were made to improve the survey based on these findings.