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The Application of Culturally Responsive Pedagogy in STEM Education

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Abstract. This paper will discuss how to integrate Cultural Responsive Pedagogy (CRP) into STEM education and achieve diversity and equity. It pays attention to three aspects: the need to offer teachers of abstract STEM courses such as physics and engineering with personalized coaching, the changes to the policy that integrate standardized measurements with the results based on the culture, and collaborative curriculum creation through the community. By reviewing the literature, The article claims that by providing such strategies altogether, under-represented students are marginalized in STEM, which allows the student population to participate in STEM, persevere, and succeed. The results have indicated that CRP may be used in the development of inclusive learning environments that link academic information with cultural attachments of students, eventually enhancing equity in STEM areas.

Keywords: Culturally Responsive Pedagogy, STEM education, teaching strategy, teaching policy

1. Introduction

STEM education is one of the anchors of the contemporary innovation but there are significant gaps. Disproportionate groups such as minority students, students whose families are poor, and first-generation post-secondary students continue to be marginalized, enrolled in smaller numbers, persevered, and poor performance in STEM majors [1]. One of the underlying reasons that have led to this gap is separation between traditional courses in STEM, which emphasizes abstract and general knowledge not grounded in the cultural life experiences and identity of various students [2].

The way forward is through Cultural Responsive Pedagogy (CRP). CRP highlights the connection of academic material to cultural contexts of students and has been revealed to be effective in making education more adaptive [3]. However, it has not been used to the fullest in the STEM realm, mostly in abstract disciplines such as physics and engineering. The paper bridges this gap by observing three major strategies to encourage teachers to deliver abstract knowledge on STEM using a cultural lens, to reform standardized assessment in order to neutralize this approach, recognize cultural backgrounds and engage the community in curriculum development. Through these points, this paper will target to design a framework of a fairer STEM education system in which every student will be able to flourish.

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2. Literature review

Over a considerable distance, researchers have emphasized the role of Culturally Responsive Pedagogy (CRP) in removing the gap in education, to a larger degree, in STEM. Smith et al. [4] and Garcia & Martinez [5] reported the effectiveness of CRP in mathematics and biology, in which the subject is easily tied to the life of the students. However, there are difficulties when it comes to more abstract subjects like physics and engineering, where there is no contextual knowledge. Nguyen [6] indicated that these areas require specially organized teaching material to make complex concepts related to the cultural knowledge system of students.

The need to reform is further demonstrated by the criticism of the traditional STEM education. Emding [2] upholds that the Euro-centered standardized-curriculum and testing system excludes the underrepresented groups of people due to abandoning their cultural backgrounds. This is supported by Ladson-Billings [3] and National Science Foundation of the United States [1], which claim that there are inconsistent evaluation systems in which the experience of diverse students is not represented, restricting the possibility of proper assessments.

Curriculum development that involves the community has been a prospective approach. Garcia & Martinez [5] and Nguyen have demonstrated that STEM materials can engage more students and be more accessible once cultural resources are included into it [6]. Simply, these researches point out that there is a very important gap:even though CRP has done well in certain STEM disciplines. Its implementation in abstract sciences and the necessity of orderly changes of assessment and the curriculum demand specific measures to acquire equity.

3. Key strategies for promoting inclusivity in STEM education

3.1. Teachers' training needs for abstract fields

The success of culturally responsive pedagogy (CRP) needs to be prepared by ensuring that the teachers are well-prepared when dealing with abstract forms of STEM disciplines such as physics and engineering. Despite the proven usefulness of CRP in other subjects such as mathematics and biology where the concepts can typically be applied in everyday life, such as identifying community resource distribution or learning about local ecosystems [4] [5]. Its application in other sciences including physics and engineering is limited due to the abstract and out of context nature of the material. These subjects are highly dependent on the theories, and those generally prevailing rules (e.g. the laws of motion stated by Newton in structural engineering, mathematical models or equations in structures) are traditionally lectured without a mention of the cultural background, and this leaves the students belonging to underrepresented groups disconnected.

The solution to this issue involves teacher training that initially identifies the unique issues to be advanced by abstract STEM material. Contrary to biology, which can enquire how conventional modes of farming are compatible with the principles of ecology, or as a study, which can make use of community budgets as the foundation upon which to teach algebra, physics and engineering often emphasise being objective, to the extent that they are taught in a cultural-free context. This solution was criticized by Emdin [2], who claims that students of other cultures do not receive equal consideration due to the fact that their culture knowledge systems are not included in these abstract models. As an example, a physics lecture on energy transfer may only mention equations such as Q = mc -T without mentioning how this activity has been historically practiced in indigenous communities, who used thermal energy in housing or how it is reused by urban communities. Lack

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of such correlations would make students see STEM as a closed-off and inaccessible world instead of the resource that might be helpful in their lives.

According to Nguyen [6], the way out of this is by gaining the power of pedagogical translation-the capacity to rebuild the abstract concepts in culturally specific terms. It is not an inborn aptitude and it requires specific training. The conventional training methods of STEM teachers tend to focus on content coverage and not on cultural responsiveness to an extent that the educators are not in a position to establish such relationships. As an example, a physics teacher is more likely to be great at explicating quantum mechanics than associating it with cultural stories, like how the stories of indigenous creation theories conceptualize matter and energy, or how the African drumming pattern are an example of wave interference. Similarly, an engineering professor can teach load bearing structures and never refer to the construction accomplishments of ancient Mesoamerican cultures and the principles of sustainable architecture of African country houses.

In order to resolve this disparity, the training programs will have to include three main components: the acquisition of cultural knowledge, adjustment in the process of teaching specific courses, and practical exposure to diverse groups of students. To begin with, the teachers must be given an opportunity to learn about cultural knowledge systems of their students. This may include the organization of workshops about the scientific tradition of local indigenous people, case studies of the progress in non-Western engineering, or bringing together the elders in the community to document how the principles of STEM are used in their daily practice. As an example, a teaching unit on the history of Polynesian navigation might examine the way the Polynesians used stellar patterns (astronomy) and the behavior of waves (physics) to traverse the distant oceans as a cultural point of departure in the learning of orbital mechanics or fluid dynamics.

Second, training should revolve around specific fields by localizing the teaching process to incorporate these cultural references. This may involve creation of lesson schemes based on problem solving situations that will be culturally relevant: such as giving students a set of problem solving activities to create a flood resistant structure based on local traditional building materials thereby, applying the engineering science principles of buoyancy and structural stability. As to physics, a course covering forces might be based on investigations into how the traditional dances or sporting activities work like the torque produced when powwow dancers spin or the projectile impact of spears in the native games. These examples do not only make abstract concepts into concrete ones, but they also acknowledge the cultural identity of students as sources of scientific knowledge.

Moreover, the training of the teachers should be integrated with the observation of practice in different classrooms where the teacher will be informed about his/her talents to implement the cultural awareness in the lesson. They can make recourse to role-playing situations, peer check-ins, and reflective dialogues. Journals are helpful to teachers to improve their teaching techniques; however, e.g., learning how to recognize when students use the knowledge of their cultural heritage in order to sort out issues and confirming that these additions are the legitimate ones in regard to STEM thinking. Over time, such a strategy will help teachers to go beyond the token acts of cultural reference (such as including one case study of a non-Western scientist) to a more profound cultural reinforcement of instructional purpose.

The effect of such training is important. As much as teachers can connect abstract STEM concepts with cultural backgrounds of the students, the students tend to believe that they can be successful in such areas. According to the study by García and Martinez [5], when the setting in STEM classrooms is culturally sensitive, the students in such settings are found to have greater levels of self-efficacy and higher engagement and also a greater sense of belonging and all these attributes are directly linked with remaining in STEM fields. As an illustration, a study conducted of

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high school physics students of Latino background revealed that the students who learned the role of Mexican-American engineers on developing sustainable water systems were more likely to pursue higher level STEM courses than students in standard classes.

In few words, abstract STEM training of teachers should not end in the delivery of the content. It ought to provide the educators with equipments to translate abstract concepts into curricula that have cultural interpretations. Through the incorporation of cultural knowledge, subject change, and first-hand learning, such programs will be able to assist teachers in bridging the divide between prevalent STEM principles and life experience of students in such challenging disciplines, eventually unlocking the potential of CRP in these dismal areas.

3.2. Policy reforms for standardized assessments

In order to have a more comprehensive STEM education, the policy changes are required so that standardized testing is resorted to with the learning outcomes being culturally-based. Since a relatively long period of time, standardized tests served as the primary yardstick to evaluate the performance of students in the STEM, but in their current form, they frequently serve as the instrument to eliminate fairness because they prioritize Eurocentric knowledge, unemotional problem-solving, a highly limited version of success. This difference between this assessment routine and the cultural reality of underrepresented students not only misrepresents the evaluation of their potentials, but also contributes to the idea that STEM does not play a role in their lives.

The flaws of the existing evaluation system are properly documented. The US National Science Foundation [1] reported that in either form, standardized STEM tests, either national mandatory tests, Advanced Placement(AP) course tests or college entrance assessment exams, all have their origin in a Western scientific worldview, which places emphasis on individual problem-solving abilities, theoretical logical thinking, and observance of rigid methodologies. As an example, a typical physics test can challenge students to determine the path of a projectile that remains in a vacuum, a situation which can have little to do with the actual problems the students of the rural setting must solve. An example would be irrigation of crops and the preservation of wildlife. In addition to this, engineering reviews tend to put considerations on design challenges in terms of urban infrastructure (e.g., the construction of bridges) as opposed to concerns about the indigenous people (e.g., installing inexpensive solar systems in remote villages or agricultural communities (e.g., enhancing the irrigation system).

This Euro-centered prejudice is complicated because analyses hardly ever devote cultural disparities in communication or expression to analysis. As Ladson-Billings [3] points, most of the standardized tests use formal academic language and linear thought which are valued by Western education, but which may not be flexible to other cultural settings. As an example, an example of native learners can be applied to solve the STEM problem using holistic, community-based knowledge and demonstrate their solutions in the form of a story or oral tradition rather than a fixed formula. Such a method is frequently discouraged in standardized tests, which require laconic, responses which fit a formula and lead to inaccurate judgment of their knowledge.

Emdin [2] also adds that the current evaluations are largely based on the retrieval of abstract information instead of the ability to transfer STEM concepts to real-life issues that are accessible to the community. The test in biology may require the pupils to name the diagrams of cells, yet not to discuss the connection between herbal facilities they use and cellular biology. Similarly, exams in chemistry might assess students knowledge on memorizing the periodic table and not their comprehension of the relationship between the preparation of home cooking and chemical reactions

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(e.g., making bread). This discrepancy would mean that students who excel in putting STEM into daily life, which is a critical skill in STEM careers, get looked over by test scores.

To address them, the policy changes have to focus on three main changes: making cultural relevance central in test design, expanding the notion of STEM proficiency to include application and community-based learning, and including a wide range of stakeholders in the process of test development.

The evaluation is first of all, requiring redesign in that it should include culturally relevant situations and problem solving partnership. This can involve introducing local problems into test questions: in a test in physics, the student may be asked to calculate the energy efficiency of solar panels used in their own community, or in an engineering test he or she may be requested to come up with a flood-response solution in their community. The assessment is also more intelligible, as the questions are incorporated into the life stories of students, thus, they become more effective in assessing whether the students know how to apply STEM knowledge. The National Science Foundation [1] proposes the notion of testing these culturally responsive assessments in the states where there is a large number of Native Americans or Latinos. The initial results indicate that the performance of students in these states is higher and less concerned with tests.

In addition, the policies will have to redefine STEM proficiency not only emphasizing the abstract knowledge but also practical work, knowledge of cultural background and collaboration. This would be compatible with the position of reality pedagogy raised by Emdin that holds that STEM skills need to be assessed based on how effectively students solve problems relevant to their community. As an example, an activity may require students to use calculus to analyze local trends of air pollution, as well as provide solutions, rather than simply testing calculus abilities. This is a task that combines both mathematical skills and environmental awareness and community participation. This assessment would more effectively reflect the abilities needed in 21 st century STEM professions which tend to give increased significance to interdisciplinary problem-solving and cultural competence.

In addition, various stakeholders should be used in the test development process, such as schoolteachers, the leaders of the community, and cultural professionals representing the underrepresented group. Standardized tests are now being developed by a collective of academicians and policy-makers who might not necessarily be well acquainted with the culture of the students who undertake these examinations. Test developers can avoid any cultural bias in the questions and make them cover the diverse experiences of students by making them involve the community members. As an example, the advice on how to structure ecological questions so that it respects traditional land management can be provided by native educators, or leaders representing Latinx community will be able to help develop the problems in engineering that relate to urban agriculture or housing affordability, which are the concerns of many Latinx students.

The benefits of such reforms are not just in the area of equitable evaluation, but also it introduces a transformation in learning and teaching. When a culturally relevant and applied assessment is considered, as the curriculum and assessment are in alignment, teachers are motivated to implement CRP in the classroom, therefore, creating a feedback loop: culturally responsive instruction makes pupils culturally responsive evaluation, which, in turn, makes culturally responsive instruction more powerful. This may eventually change the culture of STEM education practice that was a monologue approach of education into one that praises the various methods of knowledge and problem solving.

In a nutshell, standardized assessment reform is not just about fairness; it is one of the steps needed to construct a STEM education system that helps measure the potential of students properly

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and prepares all learners to the brink of achievement. Policies can transform assessment as a barrier to inclusive practice by emphasizing cultural relevance, enhancing definition of proficiency, and introducing different stakeholders to make it not a barrier to inclusive practices.

3.3. Community-focused cooperative course devising

The cultural relevance of STEM education can be reinforced by including the community in the co-design of courses, and more students can be engaged. Customary STEM programs are usually written by textbook publishers, administrators on the region scale, or scholars, with little or no involvement of the communities that have been particularly hit by the disparities in education. This top-down methodology introduces teaching resources and materials that represent the mainstream cultural norms, which results in students who belong to underrepresented groups having virtually no chances to observe their identities, past legacies, and values reflected on the content. Community-based co-design alters this format, whereby local communities are seen as equal in the process of designing STEM courses and making sure that the learning resources rely on the practical lives of the students, and cultural awareness.

The general concept of community engagement in curriculum development is anchored on the available research which shows that students would learn best when the material connects to their cultural groups. A study by Garcia and Martinez [5] on the Latino middle school science lessons revealed that students in science classes based on locally integrated systems (e.g., studying botany through family gardening or studying chemistry through traditional food-making) not only participated in science classes 30% more than students in standard textbooks classes, but also produced higher science tests scores 25% higher. On the same note, a research on Indigenous learners in Canada [6] achieved the realization that STEM courses that were co-planned with tribal elders and knowledge about indigenous ecology practices, such as wildfire management or plant harvesting, induced enrollment and augmented the cultural pride of students.

Community-based co-design is essentially a form of collaboration that brings in teachers, course takers, guardians, community heads, experts of culture as well as local units (e.g. museums, Environment-centered groups or businesses) in the process of all stages of curriculum development: laying out learning goals, developing curriculum plans, creating projects, and evaluation of results. Through this collaboration, the culture can be assured to be culturally appropriate to the community in addition to meeting the individual needs and concerns of the community. As an example, in an African-American controlled neighborhood on the coast, a collaboratively-designed marine biology course might focus on the local issues of marine pollution and coastal management, riding on the historical association of the community with fishing and management of the coast, rather than a general course on the Pacific coral reefs.

One of the most important benefits of such a strategy is that it confirms community knowledge as a credible source of STEM know-how. There are numerous underrepresented cultures that are rich in scientific inquiry, engineering discovery, and mathematical abduction that are typically denied in normal classes. As an example, the aboriginal people have invented advanced agricultural techniques, such as the Three Sisters farming system involving corn, broad beans and buttercup squash, which suggests the ecology and sustainability. Latinx practices and textile tradition have traditionally used mathematical patterns in textiles and folk art, which are examples of geometric ideas. Through combining these traditions into STEM courses, co-design honors the knowledge heritage of communities and allows the students to view STEM as a continuation of the cultural heritage rather than a foreign science.

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Community co-design also provides the assurance that the STEM content addresses practical issues in the real world that can be of significance to the students and their parents. In cities, it can refer to a direction towards STEM-based solutions to such issues as food insecurity, disparities in social services such as health, or affordable energy. In the rural communities, it might include agricultural technology, water conservation or the preservation of the wildlife. An example is the collaboration of a local community garden and high school in a low-income urban area on a conjoint project that gives students a STEM curriculum organized around sustainable farming. They also mastered biology through studying soil health, chemistry through testing water quality and engineering through constructing low cost irrigation systems all these sources helped these people in community resource and provision of fresh fruits and vegetables to the family. The project taught not only the principles of STEM, but also helped students feel that they can become a force that will transform the community.

The very process of co-design also establishes the relationship of trust between schools and communities, which is essential in improving the educational outcomes of the underprivileged students. Historically, the schools of underrepresented communities have been unaware of being looked upon as centers of imposing external values and knowledge, which leads to disengagement. The school can convey the message that they respect local knowledge and will be committed to serving community needs by involving the community members in curriculum development. With this confidence, there comes a higher involvement of the parent, the community support of school programs, and more positive school image all of which translate into student achievement.

Schools wishing to institutionalize community-based co-design well ought to have deliberate measures put in place to make it an important contribution. This comprises:

1. create inclusive cooperative environments: hold meetings at the appropriate time and place (as a community facility, house of worship), and provide translation facilities or childcare support to remove obstacles to the parents and the elders.

2. Use a stronger voice of marginalized groups of the community: It should make sure that parents, recipients of schooling, and leaders of underrepresented groups have decision-making powers and not just advisory functions.

3. Building lasting relationships: Co-design is not a one time event, but a continuous process that adapts to the different needs of the community. It provides stability and continuity through ongoing collaborations (with local non-profit or cultural institutions).

4. Incorporate the students perspectives: The students are key stakeholders, and their perspectives towards the aspects in STEM may affect the design of the curriculum. As an example, high school students would recommend the introduction of video game design (which would require coding, physical sciences, and geometry) or music tech (connecting acoustics and engineering) to the curriculum.

The issues of co-design include limited resources, time limitations and imbalance of power between teachers and the members of the community. However, these problems can be resolved through policy advocacy, teacher development in collaborative leadership, and creating regional level models that institutionalize community involvement in curriculum development.

In sum, it can be stated that community-based collaborative course development changes STEM education to a top-down arrangement to a form of collaboration, taking into account local knowledge, responding to local needs, and empowering students. This approach does not only enhance academic outcomes by integrating community knowledge in STEM content, but also helps to strengthen the connection between a school and the community where it serves, thereby creating a more comprehensive and balanced system of STEM education.

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4. Conclusion

The cultural response pedagogy (CRP) as an addition to STEM education can help move the developments towards diversity and equity in STEM fields, as portrayed in this article the three main areas to bridge these disciplines include: changing teacher training to address the special obstacles of abstract STEM learning, transforming the standardized test to align with culturally-mediated results, and allowing communities to participate in curriculum design.

Educators have to be trained to fill the gap between the abstract concepts and the cultural knowledge of students to ensure even the more complex STEM material can be relevant. The reforms in assessment policy must no longer use Euro-centered models but they should focus on the use and cultural background in evaluating the abilities of students. In the meantime, community involvement determines that the curricula should transfer the life experience of the students, recognize them and accommodate involvement.

Overall, such strategies have provided a framework of a more inclusive system of STEM education. Not only do they support underrepresented students to prosper, but they also introduce variety of thoughts in the STEM fields. In that way, CRP in STEM education erases the way to a more professional and inventive future.

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