# Teaching of Eco-Carbon Research/Production/Learning Practices by Practical Transformational Teaching Method

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# Teaching of Eco–Carbon Research/Production/Learning Practices by Practical Transformational Teaching Method

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This study applied the practical transformational teaching method (PTtM) to explore the cross–domain application learning of ecological carbon (Eco–Carbon) production and learning practice, and then linked the mechanism of carbon materials/biochar/activated carbon with learning knowledge and ability, as a wood–based related learning while establishing one of the goals of forest products career development. The study included (1) developing teaching methods that combine research results with experience and practice; (2) carrying out experimental study on the connection between the production process of the industry and the establishment of classrooms; (3) implementing characteristic academic research and industrial product development, etc. The implementation contents were (1) course teaching; (2) related Eco–Carbon practice; (3) internship report and practical briefing; (4) cross–domain teacher–assisted teaching; (5) industry visits and lectures by professional teachers; (6) creative thematic practice; (7) practical briefing and poster display, etc. Learning feedback showed that for PTtM teaching (course explanation, practice operation, speeches in cross–domain fields, visits and seminar presentation, etc.), students believed they were able to learn more knowledge in different fields and increase team thinking and communication skills by 4.54 points (satisfaction was 90.8%), and the average teachers' evaluation of National Chiayi University was 4.76 (satisfaction was 95.2%). In other words, based on students' feedback and teaching satisfaction the study is necessary to reflect on the PTtM, and continue to deepen the teaching of functional Eco–Carbon, which can achieve the real significance of the research results of the combination of students' transformational learning and teachers' theoretical teaching.

**Key words**: Practical Transformational Teaching Method (PTtM), Ecological Carbon (Eco–Carbon), Research/Production/Learning Practices, Cross–domain, Seminar Presentation

## INTRODUCTION

The classification of teachers' teaching knowledge is (1) content knowledge: which includes subject knowledge and subject teaching knowledge; (2) learners and learning knowledge: that includes knowledge of learning theory, students' physical and mental characteristics, cognitive development, motivation theory and application, and the student's background; (3) general teaching knowledge: which includes knowledge of class organization and management as well as general teaching methods; (4) curriculum knowledge: which includes the process of curriculum development, horizontal knowledge among various courses in the school, and vertical knowledge among cross–grade courses; (5) situational context knowledge: that includes various situations surrounding teachers' work such as schools, communities, students' families and society; (6) self–knowledge: which includes personal values of teachers, intentions, advantages and disadvantages, educational philosophy, expectations of students, and teaching objectives (Grossman, 1994). It appears that teachers are necessary to have a variety of teaching knowledge and abilities to be competent for teaching work. The transformation process of teaching knowledge to teaching is called "teaching transformation". It is the process of transforming self–prepared teaching knowledge into procedural knowledge of teaching behavior. Connelly and Ben–peretz (1980) report that the curriculum needs to incorporate teachers' practical experience and research, and the design of the curriculum can include both theoretical and practical experience, as well as the practical practice is indispensable for students in the pre–service stage.

Ecological carbon (Eco–Carbon) refers to the highly aromatized and insoluble solid matter produced by pyrolysis and carbonization of biomass under complete or partial hypoxia (Antal and Gronli, 2003), which can return to the soil to achieve the purpose of carbon reduction and carbon sequestration. It is regarded as an excellent soil improvement material that has an improvement effect on sandy soil, fields with poor water permeability, clay soil etc. It can provide microbial community growth characteristics to promote plant growth by utilizing porosity and high adsorption force, thereby increasing yield as well. Yang (2004) pointed out that biochar can improve sandy texture, high–salt and continuous cropping obstacle soil, poor water permeability and clay soil. It is said the Eco–Carbon can further improve the growth of vegetable and fruit trees and increase the production. Activated carbon is a porous adsorption material with a non–polar surface and effective to use activated carbon to adsorb organic substances from aqueous solutions (Tomaszewska and Mozia, 2002; Przepiorski,

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2006; Villacan *et al.*, 2006). It is chemically stable while being acidic, resistant to alkali, high temperature, and high–pressure and can be widely used in drinking water purification treatment procedures, gas phase, or liquid phase separation and purification, catalyst carrier or precious metal separation and purification, etc. (Manocha, 2003; Yorgun *et al.*, 2009; Sun and Jiang, 2010). As activated carbon has developed a pore structure it can adsorb trace organic pollutants (such as alkanes and polycyclic aromatic hydrocarbons, etc.), dyes, heavy metals, radioactive substances, and other pollutants in water (Kihn *et al.*, 2000; Andersson and Kehn, 2001; Lin *et al.*, 2016b; Lin *et al.*, 2017b; Peng and Lin, 2017). Moreover, Chemical oxygen demand and total organic carbon in water can be significantly reduced (Kunio *et al.*, 2001; Seyed *et al.*, 2004; Omri *et al.*, 2013; Lin *et al.*, 2015b; Lin *et al.*, 2017a). Activated carbon affects both turbidity and chromaticity of physical standard in drinking water (Anu *et al.*, 2006; Lin *et al.*, 2015b) and has an inhibitory effect on the total bacterial count, and *Escherichia coli* and coliform group in the water (Ogawa *et al.*, 2011; Lin *et al.*, 2016a; Lin *et al.*, 2017a) as well.

There is a correlation between the amount of organic matter contained in the biochar or activated carbon prepared by pyrolysis, multiple porosity characteristics, and the specific surface area. They can be applied to different levels according to the characteristics obtained by different preparation methods. This study intended to introduce the research results into the course teaching and to take the production and learning practice, and cross–domain practice as the method as the goal of students' learning. The purpose of this teaching research was to plan students' knowledge–seeking practice and cross–domain construction method of Eco–Carbon by the teaching method of Research/Production/Learning Practices with self–designed of the practical transformational teaching method (PTtM). The implementation content was to introduce the research results of "functional Eco–Carbon" into the course teaching. Moreover, the practice of Eco–Carbon production and learning was matched with cross–domain application practice, thus linking the mechanism of carbon materials/biochar/activated carbon with learning knowledge and ability by improving the teaching quality and promoting the learning effect of students and the teaching practice of teachers. As the goal of wood–based related learning and the establishment of forest products career development, the research covered:

1. Develop the teaching method by combining the research results of "functional Eco–Carbon" with the production and learning experience and the practice of seeing and learning.
2. Learn the application of industrial carbon materials/biochar/activated carbon production procedures and establish industry classroom connection experiments.
3. Implement the academic research of "Eco–Carbon" characteristics and the products development of carbon materials/biochar/activated carbon industry.

## RESEARCH METHODS

### Preparation and objects

The first six months of this teaching research were the compilation of teaching materials for Research/Production/Learning Practices of functional Eco–Carbon, and the preparation for cross–domain practice. During the six months after the study, the courses were conducted i. e. course teaching and practical practice, assistant teaching by industry and cross–domain teachers (agronomy/food/aquatic and industry, etc.), teaching evaluation, practice report writing, practical briefing, and participation in creative topic publication, etc. The research objects were students who selected "Ecological Carbon Science and Application" as the course. The students were need to be junior and they had learned basic and core courses from the first semester of their freshmen year, including Introduction to Agriculture, Biostatistics, Material Science and Wood Histology/Physics/Chemistry and Seasoning/Preservation, Forest Products Chemistry, etc.

### Design of course contents

Course title was "Ecological Carbon Science and Application". The research results were taken as the theme in course teaching and attention was connected to the learning results. The course planned student's learning, knowledge practice, cross–domain construction, and implemented cross–domain application practice and knowledge. Furthermore, learning linking carbon materials/biochar/activated carbon mechanisms was one of the goals of wood–based related learning and the establishment of forest products career development. The practice of "functional Eco–Carbon" in carbon production and learning of teaching contents and methods were matched with cross–domain application practice. It was divided into general research results and items of carbon materials/biochar/activated carbon mechanism and learning knowledge and ability, and carried out with unit themes, specific contents of teaching, practice teaching, and evaluation methods as shown in Table 1.

### Implementation contents and learning feedback

This study compiled the teaching materials for the subject of "functional Eco–Carbon". It collected data from 24 domestic and foreign research journals (see this paper' REFERENCES), 6 invention patents (Table 2) won by Taiwan, ROC, and the other referenced literatures. The main research results put forward a clear summary of the professional outline and the content of the context antecedents and consequences to guide students into the range of the research. The core of course covered the issues to be discussed, the importance of solving this problem, current research results on this issue (review), the advantages and disadvantages of related research, differences in research results, and the benefits of research methods.

The students then took the professional internship and learned the correctness and superiority of theoretical analysis. By comparing and inferencing from these

**Table 1.** Research/Production/Learning Practices holistic course–design items for course – “Ecological Carbon Science and Applications”

| Item | Unit theme | Specific contents of teaching | Practice teaching | Evaluation method |
|---|---|---|---|---|
| Carbon materials | Applied to cultivation medium required for plant growth | Prepared carbonaceous material as a carbon material for an alternative for the substrate of cultivation medium | Practice on physicochemical properties in cultivation medium | Writing internship report |
| | Development of biomass energy materials | Combining “carbon” with high heating value to develop biomass energy materials, and “moving towards a low–carbon future” to make good use of renewable energy; planning “carbon capture and storage” development | Practice on evaluation of heating value of carbon materials in extreme value theory/Dulong formula | Substantive briefing |
| Biochar | Enhancement of plant productivity applied to agriculture | Customize cultivation substrate and soil–holding organic materials, etc., increase the related water retention, fertilizer retention, ventilation of soil on water, oxygen, and nutrients in planting and cultivation, etc. | Explain the practice of cultivation medium substrate and soil functional materials | Writing internship report |
| Activated carbon | Functions for purifying/adsorbing contaminants | Developed into materials for drinking water filtration and related materials for gas phase adsorption | Practice of water purification procedure and water quality inspection | Writing internship report |
| | Substitutability of derivative products applied to related industrial materials | Food water activity system, oil fume thermal adsorption substrate (mat; board), and organism safety assessment | Practice of moisture–proof water activity and moisture absorption of food | |
| | | | Practice on antibacterial activity of activated carbon | |
| Eco–Carbon | Understand the utilization evaluation of carbon footprint/carbon sequestration/carbon cycle by each item | Environmental–friendly functional materials provide as the Ecomaterials’ description of natural resources for carbon production | Calculation practice of carbon footprint/carbon sequestration/carbon cycle assessment | Creative thematic publication |

results and by adopting “analysis and discussion” and “practice and investigation”, students were able to discuss some possibilities or put forward their experiences and opinions for theoretical analysis and practice. By comparison with other methods, students understood the correctness, appropriateness, and feasibility of the theoretical basis to highlight the problems and realized the contribution of research; prepare internship report, practical briefing, and direction reference in creative thematic publication. Students could share their experiences, introduce themes into course teaching, and conducted the practice of carbon production and learning combined with the cross–domain application. The enhancement of agricultural plant productivity, the function of purifying/adsorbing contaminants, the mechanism utilization of Eco–Carbon, the application of derivative products in related industrial materials, the evaluation of the environment, and carbon footprint/carbon sequestration/carbon cycle, enable students to better apply Eco–Carbon resources in research and industrial practice were arranged.

The survey of teaching opinions on research, production, and learning Eco–Carbon science and application was taken after the course, and the questionnaire included (1) the explanation on the teaching purpose and course content to students; (2) practice operation was helpful to learn and understand the course content; (3) teachers’ speeches in various fields were clear and organized and the students might learn more; (4) the visit to the bamboo charcoal kiln was helpful for students to understand the preparation process of bamboo charcoal; (5) presentations for a deeper understanding of the application of Eco–Carbon; (6) training students’ reporting ability through special subjects’ publication and arousing their ability to think about problems; (7) teaching this course in different ways were able to improve students’ learning effectiveness and enhance students’ team thinking and communication skills.

**Table 2.** Invention patents used in this study

| No | Title of invention patent | Patent country/number | Patent duration |
|---|---|---|---|
| 1 | THE PREPARATION METHOD OF ACTIVATED CARBON (AC) FROM THE SORGHUM DISTILLERY RESIDUES (SDR), INCLUDING RICE HUSK AND SORGHUM SHELL | Taiwan, ROC/I481556 | 20150421–20321121 |
| 2 | THE PREPARATION METHOD OF "BIOMASS SORGHUM DISTILLERY RESIDUES FUEL BRIQUETTES (BioSOFT) FROM SORGHUM DISTILLERY RESIDUES AND HIGH FIBER HERBIVORE ANIMAL EXCREMENTS | Taiwan, ROC/I549762 | 20160921–20350422 |
| 3 | A TYPE OF FOOD MOISTURE-PROOF MATERIAL (MOPROMAT) PREPARED WITH SORGHUM DISTILLERY RESIDUE ACTIVATED CARBON (SDRAC) AND ITS MADE METHOD | Taiwan, ROC/I626355 | 20161122–20350413 |
| 4 | ONE OF THE METHODS FOR PREPARING HIGH PURIFICATION FUNCTIONAL ACTIVATED CARBON FROM SORGHUM DISTILLERY RESIDUE AND ITS APPLICATION | Taiwan, ROC/I561465 | 20161211–20350314 |
| 5 | A METHOD FOR PREPARING SORGHUM DISTILLERY RESIDUE BIOCHAR (SDR BIOCHAR) WITH FUNCTIONAL CULTURAL MEDIA AND ITS APPLICATION | Taiwan, ROC/I602796 | 20161021–20350528 |
| 6 | THE SORGHUM DISTILLERY RESIDUE CARBONS WITH ENIVRONMENTALLY FRIENDLY EFFECTIVENESS | Taiwan, ROC/I660911 | 20190601–20371010 |

## RESULTS AND DISCUSSION

### Course framework and contents

The common forms of practice in the Department of Wood–Based Materials and Design, National Chiayi University (NCYU), Taiwan included visiting in related industries, laboratory experiments, and factory practice. The research first provided students with practical knowledge (research results) and then transformed them into a learning theoretical basis. According to this overall curriculum framework of teaching research, the course framework and contents are shown in Fig. 1.

The framework of the course was to introduce the research results of carbon materials/biochar/activated carbon into the teaching content of the course and to learn from the practice of carbon production, and to study in coordination with cross–domain application practice. Moreover, covering the practice of physicochemical properties of agricultural cultivation medium materials, practice on evaluation of heating value for carbon materials in extreme value theory, Dulong formula and actual sampling points–selected, practice in water purification procedure and water quality inspection, practice on water activity, and moisture absorption of food moisture–proof, a practice on antibacterial activity of activated carbon, practice in the calculation of carbon footprint/carbon sequestration/carbon cycle assessment. The basic learning area for the Eco–Carbon mechanism, preparation conditions/methods/procedures, and methods of knowing their basic theories and characteristics were linked. The above transformation process was called "Practical Transformational Teaching Method (PTtM)" which was compiled into teaching materials. Based on these learning process students were able to study teaching materials after learning the research results first and then learning the basic theories. The students carried out academic research upon graduation for master's and doctor's classes related to wood–based, or when entering the forest products–related careers, and also had the ability to develop Eco–Carbon related products.

This teaching included a compilation of research results in the first three months into text materials, and briefing documents The teaching materials combining the research results with production and study experience and practice were compiled. The following three months were for the design and arrangement of cross–domain application practice and the preparation of materials and instruments. That was the establishment of application face–to–face learning such as industry classroom connection experiment. In the second six months of the course teaching and practical practice, industry internship, and cross–domain teacher–assisted teaching (agronomy/food/aquatic and industry etc.) were introduced to the students as the elective courses. The teaching evaluation which was divided into practice report writing, practical briefing and participation in the creative thematic publication was applied.

The teaching progress of this course "Ecological Carbon Science and Application" (Table 3) was compiled and it was included in the elective course of the third year of the Department of Wood–Based Materials and Design, NCYU. The learning goal of this course was to introduce research results (see this paper' REFERENCES) into the

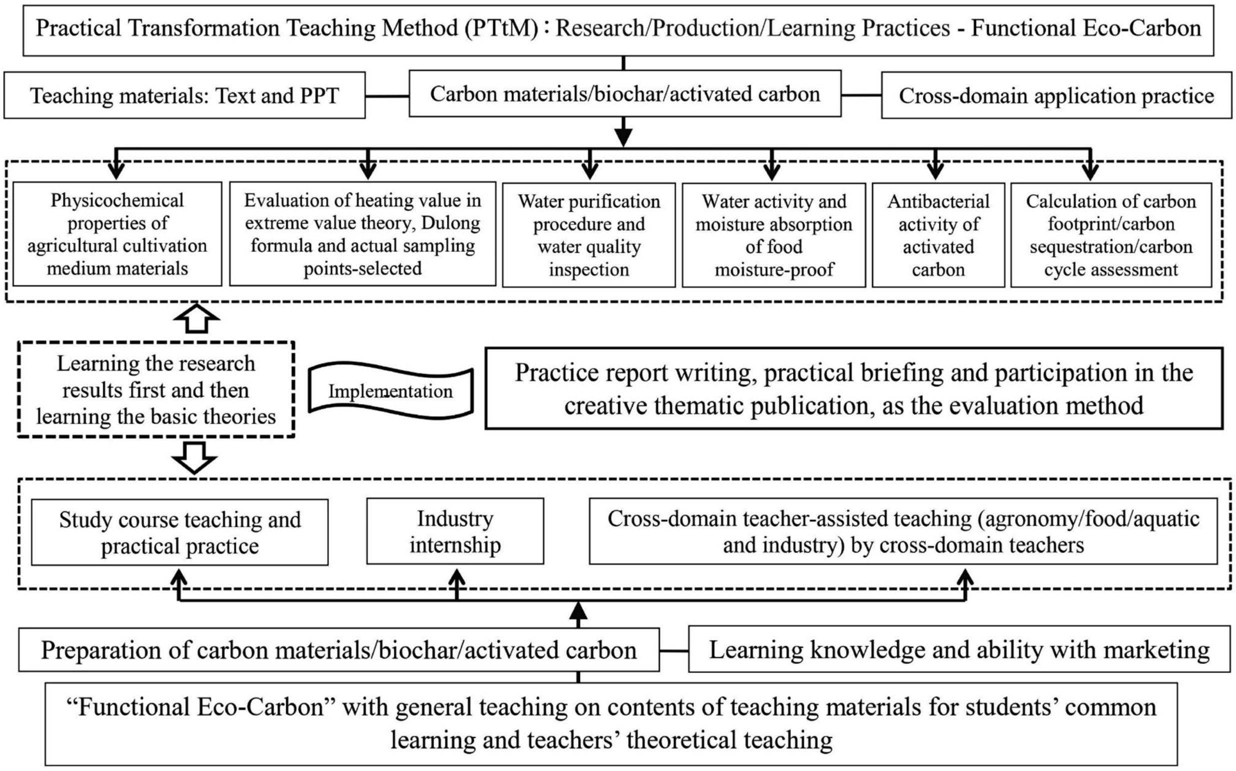


**Fig. 1.** Course framework of "Research/Production/Learning Practices" in Practical Transformation Teaching Method (PTtM).

**Table 3.** Teaching progress of course – "Ecological Carbon Science and Application"

| Week | Subject | Teaching contents | Teaching method |
|---|---|---|---|
| 1 | Teaching syllabus | Scope of Eco–carbon science and application | Lecture, introduction to PTtM |
| 2, 3 | Chapter 1 Preparation of Eco–Carbonized Materials | Development of multi–functional Eco–Carbon | Lecture, competence learning |
| 4 | Chapter 2 Application of Eco–Carbonized Materials | Mechanism and application of carbon materials/activated carbon, and vinegars | Lecture, competence learning |
| 5 | Industry Internship–Bamboo Charcoal Kiln Apprenticeship and Exhibition Visit (Bamboo Charcoal Kiln and Sales Exhibition Market) | | |
| 6–7 | Chapter 3 Science of Gas–Liquid Adsorption of Carbon Materials | Function for purifying/adsorbing contaminants | Lecture, cross–domain courses |
| 8–9 | Chapter 4 Application of Carbon Materials in the Food Industry | Evaluation of moisture–proof/preservation/adsorption efficiency of food | Lectures, cross–domain courses |
| 9 | Internship Report and Practice Briefing Notes | Strengthening of cross–domain auxiliary teaching courses | Mid–term link learning |
| 10 | Chapter 5 Development of Biochar Energy | Development, substitution, and future of biomass energy source | Lecture, cross–domain courses |
| 11–12 | Chapter 6 Application of biochar in Planting and Cultivation | Biochar cultivation medium and soil functional materials | Lecture, cross–domain courses |
| 13 | Chapter 7 Concept of Eco–Carbon in "Ecomaterials" | Assessment of carbon footprint/carbon sequestration/carbon cycle | Lecture, competence learning |
| 14–15 | Internship I Function of Derivative Carbon Application | Water activity, absorption/desorption and water purification | Property theory/ experimental |
| 16–17 | Internship II Biological Antibacterial Activity of Eco–Carbon | Practice of total bacterial count, and *Escherichia coli* and coliform group, etc. | Applied learning/ experimental |
| 18 | Final exam (self–leaning) | Creative thematic publication | Internship report/practice PowerPoint |

Learning resources: The course is mainly based on dictation "self–compiled handouts, teaching practice research/E–learning https://ecourse.ncyu.edu.tw/ /literatures/patents, etc.". The evaluation method includes briefing documents, PowerPoint and film viewing explanations, etc.

course teaching and used teaching research (Table 1)/ NCYU E–learning teaching platform https://ecourse.ncyu.edu.tw/ /ecological exploration related literatures (see this paper' REFERENCES)/personal research patents (Table 2) as supplementary teaching.

**Specific contents of teaching**

This teaching was interdependent with the above subjects of Table 3. It introduced the links of students participating in teaching to the application of industrial practice, professional knowledge was put into practice, and allowed students to learn both knowledge and ability with the development of the industry. The students were able to shorten the gap between learning and application while achieving professional ability and realizing the goal of wood–based related studies and career development. This not only linked and transforms teaching and industrial application with the characteristic academic research of functional Eco–Carbon, but also fostered the development of industrial products and the combination of cross–domain & border professional teachers. It therefore used carbon materials–cultivation media required for plant growth, such as: carbon–containing substances were prepared into carbon materials as substitution materials for cultivation medium substrates. And biomass energy materials were developed by combining the high heating value of "carbon" with the self–binding characteristics of high lignin resources as another development mode of wood combustion particles/pellets. Besides, biochar was used as a substrate material for customized cultivation media and soil–holding organic materials to increase water retention, fertilizer retention, and ventilation of soil for water, oxygen, and nutrients in cultivation. Activated carbon was used for purifying/adsorbing contaminants, developing materials for filtering drinking water, and materials related to gas–phase adsorption. Its derivative products were also substitution of materials for food–related industries, and were the preservation material of the food water active system, and the base material of oil fume thermal adsorption and filtration materials, such as edible inferior oil, were developed. Inferentially, Eco–Carbon was able to provide the insight into each carbon material under the final environmental consideration, and the use of carbon footprint/carbon storage/carbon cycle assessment to become materials with environmental protection and Ecomaterials, thus achieving the goal of "essentially transforming the research results of student's learning and teacher's theoretical teaching".

Eco–Carbon prepared from some of plants, animals, or minerals with high carbon content as the precursors. For example, plant stems (Blankenhorn *et al*., 1978;

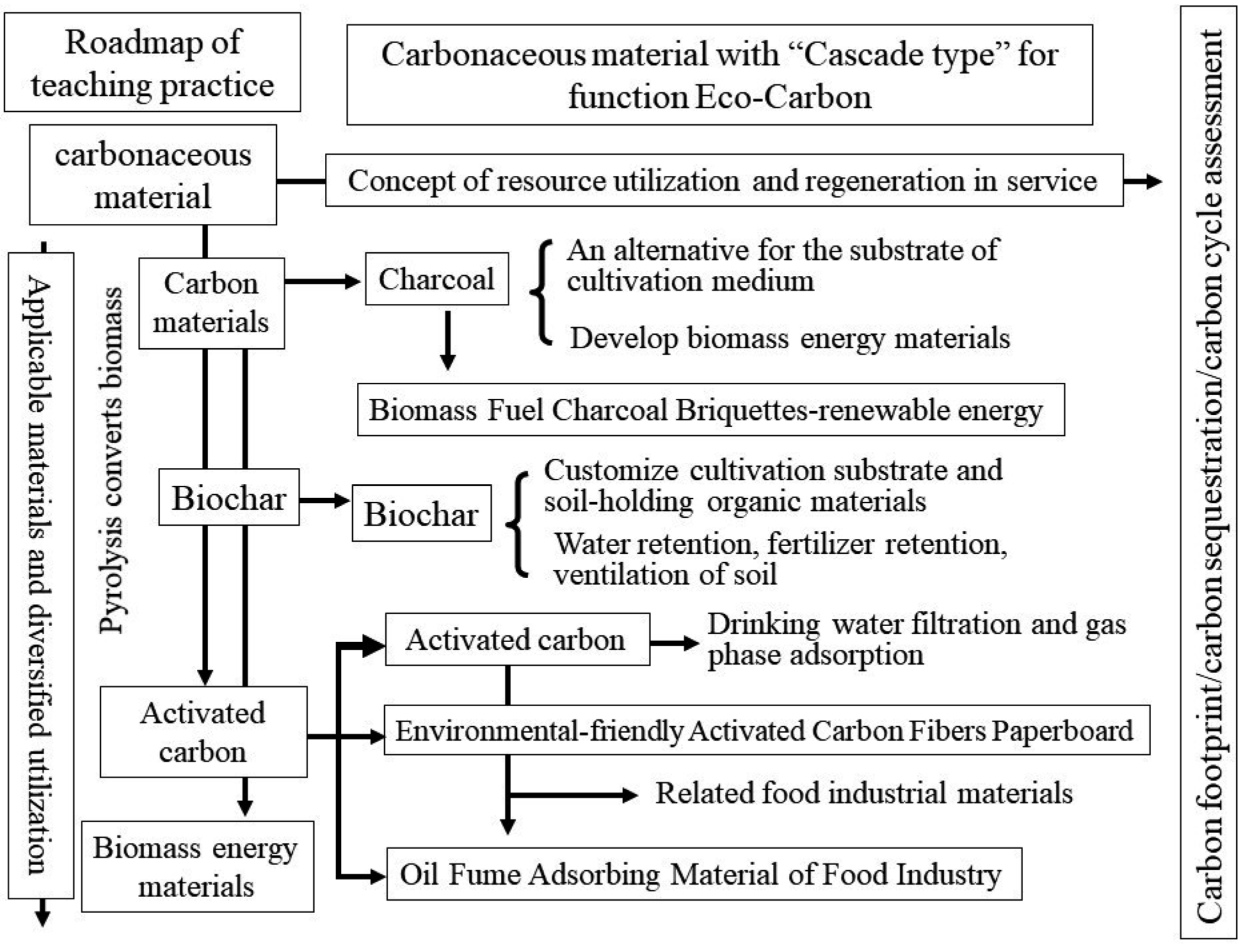


**Fig. 2.** Roadmap of academic research and industrial product development with PTtM.

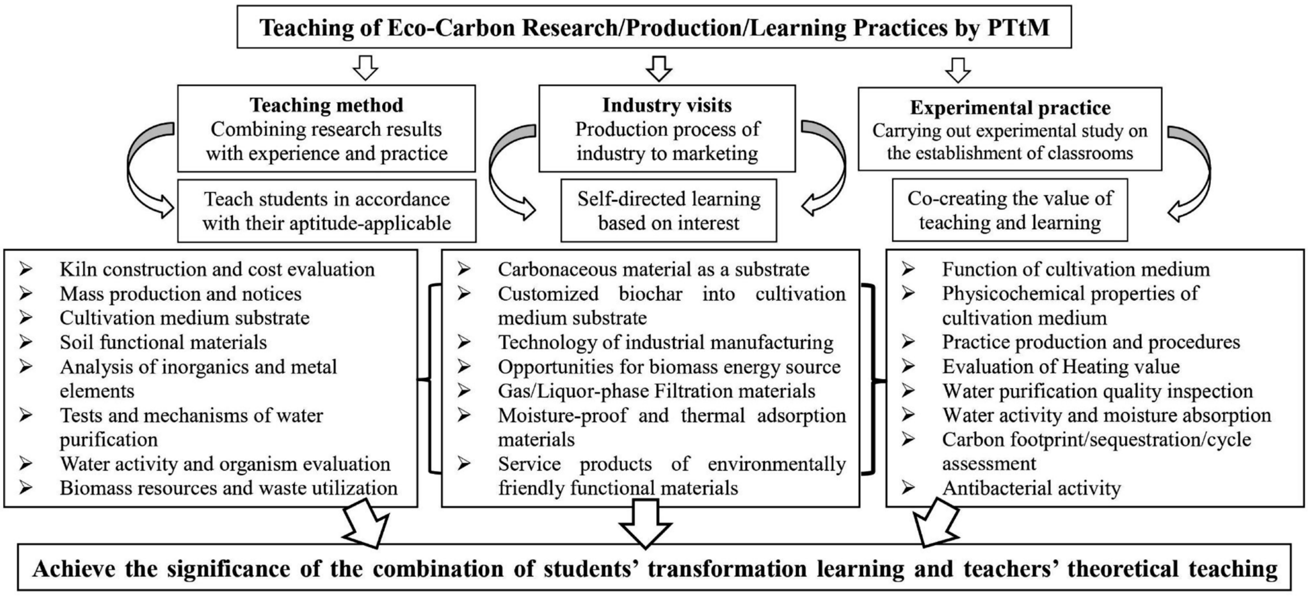


**Fig. 3.** Contents of academic research connecting application topics of products development in "Eco–Carbon" industry with PTtM.

Baileys, 1979; Baileys and Blankenhorn, 1982; Aworn *et al.*, 2008; Peng and Lin, 2015; Lin *et al.*, 2017a), shell, kernel (Hayashi *et al.*, 2002; Ahmedna *et al.*, 2004; Marsh, 2006), corn cob and corn stalk (Sun and Webley, 2010; Sych *et al.*, 2012; Lin *et al.*, 2014), coconut shell (Daud and Ail, 2004; Li *et al.*, 2008; Lee *et al.*, 2011), sorghum distillery residue (Lin *et al.*, 2015a, b) animal bones, peat, lignite, bituminous coal, tar or asphalt (Marsh, 2006), and other synthetic polymers such as mucus rayon, polyacrylonitrile, phenolic aldehyde (Manocha, 2003) or rubber, etc. were prepared by pyrolysis. The application or additional product value of the prepared carbon materials/biochar/activated carbon was able to increase its multi–purpose and benefit the country and the population, not only be regarded as a forward–looking material but also provide another thinking for resource reproduction and utilization. This "Road Map" of teaching practice took the research results as the primary content as shown in Fig. 2.

Moreover, this teaching contents were written in various journals (see this paper' REFERENCES) to compile the value–added of teaching practice and teaching materials, which were used as cross–domain courses and application topics of production and learning. It was supplemented by the probation of industry production procedures and establishment of industry classroom connection experimental learning, as shown in Fig. 3.

**Connected course with cross-domain teaching**

The course "Ecological Carbon Science and Application" was taught and connected in departments of cross–domain research cooperation, as followed.

1. Carbon materials (Department of Wood–Based Materials and Design) & culture medium required for plant growth (Department of Agronomy/Horticulture): prepared carbonaceous material was as carbon materials to be substituted for culture medium substrates;
2. Biochar or charcoals (Department of Wood–Based Materials and Design): biomass energy materials were developed by combining a higher heating value of "carbon" with the self–binding characteristics of high lignin resources as another development mode of wood combustion particles/pellets;
3. Biochar (Department of Wood–Based Materials and Design) & enhancement of Agricultural Plant Productivity (Department of Agronomy/Horticulture): as a substrate material for customized cultivation media and soil–holding organic materials, to increase the soil's related water retention, fertilizer retention and ventilation of water, oxygen, and nutrients during cultivation;
4. Activated carbon (Department of Wood–Based Materials and Design) & the function of purifying/adsorbing contaminants (Department of Aquatic Biosciences): developed into materials for drinking water filtration and materials related to liquor–phase adsorption;
5. Activated carbon derivatives (Department of Wood–Based Materials and Design) & substitution of materials for food–related industries (Department of Food Science): as a storage material for food water active systems (gas–phase adsorption), a base material for oil fume thermal adsorption and filtration materials such as edible inferior oils.
6. Through insight into various carbon materials – Eco–Carbon (Department of Wood–Based Materials and Design) & the utilization evaluation of carbon footprint/carbon sequestration/carbon cycle (Department of Forestry and Natural Resources): provided as the environmentally friendly materials (Ecomaterials), and an environmentally conscious concept of resource application to carbon production.

The cross–domain department projecting series and contents were covered by the carbon materials/biochar/activated carbon mechanism and learning knowledge:

1. Department of Agronomy/Horticulture I – Ideal media such as physicochemical properties of plant growth: porosity/medium water capacity/total porosity/total density/pH value/EC value/CEC, etc.
2. Department of Agronomy/Horticulture Ⅱ – Cultivation medium substrate and soil–holding organic materials (biochar): Described as a cultivation medium with water and fertilizer conservation and providing oxygen diffused to roots.
3. Department of Wood–Based Materials and Design – Biomass energy source with "carbon" high heating value: including heating value of extreme value theory, Dulong formula, and actual sampling points–selected, heating value effect, energy yield, and energy density, etc.; the heating value were used to evaluate and explain.
4. Department of Aquatic Biosciences – Development of activated carbon with high adsorption efficiency: teaching items: yield, iodine value, methylene blue adsorption, true density, BET specific surface area, porosity, and nitrogen adsorption and desorption isotherms.
5. Department of Food Science – Evaluation of food moisture–proof materials: water activity measurement and simulation of hygroscopic ability of activated carbon in various environment systems; organism safety assessment, etc.
6. Department of Forestry and Natural Resources – Assessment of carbon footprint/carbon sequestration/carbon cycle teaching: carbon not only carbon sequestration from carbon dioxide absorbed in plants, but also sequestrated carbon into the soil, reducing the need for carbon–intensive fertilizers. It was also stored in the soil to improve fertility and promote crop yields.

**Course related development**

To give full play to the regeneration of environmental resources and the future utilization of biological functional materials, this teaching also taught students to develop additional new products with added value and capability by considering people and effectively uses the connection between industry and academic research (Fig. 3). Furthermore, it gave full play to the regeneration of research resources, and to become the possibility of creating an Eco–Carbon industry "three industries and four modernizations". The following explains the feasibility of implementing research and development for the industry with various functional Eco–Carbon derivatives in this developed implementation:

1. The preparation of customized ecological carbon–based cultivation medium substrate replacement materials and soil–holding organic materials can regard natural carbon–containing precursors as research and development materials for cross–domain products. It can strengthen the productivity of agricultural plants and make them become industries with characteristics and a combination of science and technology as resources generated by industrial manufacturing and processing.
2. Through the development of biomass energy materials developed by carbon combustion combined with biomass gluing characteristics, the feasibility of being a biomass energy material source can not only reduce the initial investment cost but also make the newly established companies profitable by using this technology. The companies can be scaled to foreign countries, thus achieving the opportunity of internationalization of manufacturing industry services.
3. The prepared water source filtration materials and gas phase adsorption materials are extended to the related industries of water plant purification and pulp mill pollutant adsorption so that the original manufacturing–oriented products become scientific and technological products.
4. The developed the environmentally friendly materials – activated carbon moisture–proof materials and thermal adsorption plates can be applied to food–related industries. The original carbon industry has been transformed from traditional manufacturing to a characteristic industry.
5. To solve another thinking of biomass reproduction and utilization at present by understanding the evaluation of carbon footprint, carbon sequestration, and carbon recycling. It can become an environmentally friendly functional material and then be used in related industries to become an environmentally friendly service product.

At the same time, this teaching research was in line with the positioning of NCYU as a comprehensive university with excellent teaching and integrating characteristic research and industrial practice and the student–oriented concept of "serving the society with knowledge, leading progress with science and technology and beautifying life with humanity". Attention was able to be paid to the learning effectiveness and fulfill the social responsibility of leading the industry. Take the "Three–Five Projects" of the school planning as the blueprint for development and invest in the cross–domain characteristic research and creative topic publication of the three–innovation research. In teaching practice, the learning development of teaching field transformation and innovation evolution through the curriculum transformation of the three instructions teaching has been achieved, and the vision of "Pride of Chiayi–Internationally Recognized–Nationally Renowned" is jointly pursued.

## CONCLUSION

The teaching results showed that planning student's study of Eco–Carbon specialty with the PTtM of "Research/Production/Learning Practices" had the value of transformation and co–creation of teaching and learning, while linking the mechanism of carbon materials/biochar/activated carbon with the knowledge and ability of industrial practice were able to strengthen students' autonomous study of professional ability. During the implementation process in the course, it was found that the PTtM of functional Eco–Carbon needed the assistance of characteristic academic research, industrial product development, and the combination of cross-domain & border professional teachers. It probably linked with industrial application to achieve the significance of the combination of students' transformation learning and teachers' theoretical teaching. The functional Eco–Carbon practice with the PTtM was to "(1) integrate research results with the teaching content of production and learning practice; (2) implement the teaching methods with industrial application; (3) establish the experimental study linked with industrial classrooms". Links of students' participation in the application of industrial practice was able to be introduced to put professional knowledge into practice in teaching. Through solid cross–domain internship courses, students' knowledge was able to be developed with the industry and achieve the Ministry of Education's goal of implementing teaching innovation. Also, strengthening the cultivation of talents in schools, and promoting teaching practice research in colleges and universities, thus shortening the gap between learning and application and truly achieving the curriculum transformation and the cross–domain study of the "Three–Five Projects" of NCYU's school planning.

## AUTHOR CONTRIBUTION

Han Chien LIN designed the study, performed the course/experiments, provided resources, evaluated data with the statistical analysis and wrote the paper. Noboru FUJIMOTO supervised the work. The authors assisted in editing of the manuscript and approved the final version.

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