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USING A THREE-TIER MULTIPLE-CHOICE DIAGNOSTIC INSTRUMENT TOWARD ALTERNATIVE CONCEPTIONS AMONG LOWER-SECONDARY SCHOOL STUDENTS IN TAIWAN: TAKING ECOSYSTEMS UNIT AS AN EXAMPLE

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Abstract. *This research is conducted to identify the scientific conceptual cognition of ecosystem and the corresponding alternative conceptions by lower-secondary school students in Taiwan. Concept mapping, interviewing, and two-tier diagnostic test cannot make explicit reasoning pathways that students may use. Therefore, its purpose is to develop, validate, and utilize a three-tier multiple-choice diagnostic instrument for the ecosystem concept (TDIEC). The instrument can assist teachers in analyzing their students' reasoning. This does not only distinguish alternative conceptions from lack of knowledge but also determines the percentages of false positives and false negatives. One hundred and six students were tested with this instrument in Taiwan. The data analysis reveals common alternative conceptions shared by students, indicating that 35.59% of the samples had inaccurate conceptualizations of ecosystems. Common alternative conceptions of ecosystems include the following: (i) Only biological components constitute an ecosystem; (ii) The Venus flytrap and pitcher plants are preys; (iii) Competition is synonymous to predation; (iv) Ecological balance refers to the sustainable circulation of energy and matter in the environment; and (v) The simpler the species, the more stable the ecosystem. It concludes with the interpretation of the results, suggestions for the application of the TDIEC, and correct alternative conceptions in Ecology classes.*

Keywords: *Three-Tier Diagnostic Instrument, ecosystem concepts, alternative conceptions, lower-secondary students*

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Introduction

Learning facilitators have come across several fallacies and alternative conceptions during their interactions with lower-secondary school students of different levels and educational background. It burdens them to think of the consequences of the students' misconceptions which, when left uncorrected, might influence others as well as the next generation. Hence, this research study has been conducted. Gilbert and Watts (1983) stated that when learning scientific concepts, students often use their existing knowledge to understand or construct new knowledge, concepts, and imageries. In other words, personal experiences may affect the interpretation of knowledge. Therefore, the understanding of a student's newly learnt knowledge may be a concept different from or a misunderstanding of the content taught by the teacher. These misconceptions due to misunderstanding are known as alternative conceptions.

Students' alternative conceptions tend to be very different from the abstract scientific conceptions (Asghar et al., 2019). Potvin (2017) pointed out that discovering what students' commonsensical concepts are and how they use them to process scientific issues logically is of importance in science education. Dreyfus and Jungwirth (1989) found alternative conceptions are long-term; however, because these conceptions do not have learning functions in the classroom, teachers tend to ignore them. Sander et al. (2006) found alternative conceptions of the ecosystem appear with high frequency in the samples of elementary school students. Moreover, these alternative conceptions usually last through adulthood and do not change over time.

It has been found that the knowledge of lower-secondary school students' alternative conceptions does not only allow science education stakeholders to understand students' cognitive structures before learning but it also provides a basis for improving the effectiveness of science teaching and correcting alternative conceptions. Biology educators (Alexander, 1982; Manzanal et al., 1999; Allen, 2016) have noted that students' understanding of the food chain is at

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the heart of understanding more complex ecological patterns. Different plants and animals depend on each other for survival, and understanding this interdependence is the cornerstone of Biology education. These ecosystem concepts are vital to understanding more complicated problems, such as environmental concerns, population administration, food supply, and secondary and tertiary food pollution (Barman et al., 1995). The dilution effect of biodiversity in ecosystems is effective in preventing the spread of diseases such as West Nile disease (Allan, 2009), and Lyme disease (Dybas, 2001). Students of today may later become citizens who are responsible for individual and community orientation, for decisions on ecological and environmental problem solutions. Because their comprehension of ecological concepts can affect the decision -making process (Zimmerman & Cuddington, 2007), it is necessary to diagnose students' misunderstandings as early as possible in order to help reduce the buildup of mistaken concepts that may lead to negative consequences in the future.

Researchers have proposed some methods for exploring students' alternative concepts. However, these forms of diagnoses have proven to be very time consuming and are, therefore, not economical (Tongchai et al., 2009). Duncan and Johnstone (1973) emphasized that the traditional multiple-choice pen-and-paper test cannot make explicit reasoning pathways that students may use. Fully revealing the diversity and intricacy of students' thinking is a significant challenge in the development of concept assessment (Smith & Tanner, 2010). Haslam and Treagust (1987) reviewed issues related to alternative concepts in literature. In order to ensure that subject matters have provided substantial learning benefits, a two-tier diagnostic test has been used to help teachers gauge whether or not students have alternative conceptions. Unfortunately, two-tier tests have limitations. Specifically, these tests do not discriminate or analyze the lack of knowledge in alternative conceptions (Arslan et al., 2012). To get the better of this limitation, three-tier tests were developed. The third tier inquires whether the student is confident in his/her previous two answers (Peşman & Eryılmaz, 2010).

Oberoi (2017) developed a three-tier diagnostic test to determine lower-secondary school students' alternative concepts in an ecological environment unit and to analyze the reliability and effectiveness of the test tools. However, the study did not elaborate or describe lower-secondary school students' misconceptions of ecosystems. Distinguishing alternative conceptions and differentiating them from lack of knowledge is very important in educational research. However, related studies are limited (Arslan et al., 2012). However, the current study contributes to literature by developing a reliable and valid three-tier diagnostic test on ecosystems to assess lower-secondary school students' alternative concepts in this domain.

This study helps develop a deeper understanding of Taiwanese lower-secondary school students' current ecosystem concepts. The study is based on the three stages of developing diagnostic tests proposed by Treagust (2007) and Peşman and Eryılmaz (2010) in order to develop a three-tier multiple-choice diagnostic instrument of the ecosystem concept (TDIEC). The three-tier diagnostic paper test was administered to Taiwanese lower-secondary school students to determine what alternative conceptions of the ecosystem they hold. The hypothetical questions in this study are as follows: (i) Should the TDIEC results be a valid and reliable measure of Taiwanese lower-secondary school students' qualitative understanding of ecosystems? (ii) What alternative concepts of ecosystems do Taiwanese lower-secondary school students have?

Literature Review

Scientific Concept of Ecosystem

An ecosystem is a community of living organisms that interact among each other and with the nonliving components of their environment as a whole system (Smith et al., 2012). Ecosystems are essential for supporting life on earth. The biological resources, predation, parasitism, and symbiosis as well as the interaction between and among these organisms are the major determinants of species distribution and abundance (Jones et al., 1994). In fact, the variety of products and services that people depend on for survival are derived from the resources in the ecosystem (Costanza et al., 2014).

Lower-secondary school students need to understand how ecosystems work, as it is an essential part of environmental knowledge (Jordan et al., 2013). However, due to the complexity and dynamic processes of ecosystems (Hmelo-Silver et al., 2007), learning about ecosystems and the interdependence of the system's components is quite difficult (Gallegos et al., 1994). Gilbert and Watts (1983) noted that when learning scientific concepts, learners often use their existing knowledge to understand or construct new knowledge, concepts, and imageries. Because a student's personal experiences may affect his interpretation of a concept, educators need to diagnose students' alternative conceptions, which has shown to influence subsequent learning (Garnett et al., 1995).

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Lower-secondary School Students' Alternative Biological Conceptions

Hancock (1940) pointed out that alternative conceptions should not be viewed as coherent frameworks. Rather, these conceptions are the result of faulty reasoning. Alternative conceptions are also an essential part of conceptual change and reconstruction. Ausubel (1968) wrote that students can use existing concepts to correlate with new knowledge. Not only can new knowledge be incorporated into existing cognitive structures, but the latter can also be changed or reconstructed accordingly. Therefore, active teaching modes or strategies can help learners make sense of something from their learning, beginning with defining the teaching objectives to achieve a conceptual understanding through reconstruction and onto conceptual change. Trowbridge and Mintzes (1988) conducted a cross-age analysis of elementary, secondary, and college-level students' alternative conceptions of animal classification, in which they found out that the students had quite a few alternative conceptions that have not changed throughout the school year.

Cardak (2009a) observed that elementary and lower-secondary school students have some alternative conceptions of dangerous animals in the environment. For one thing, students believe that vertebrates are more dangerous than invertebrates. Cardak (2009b) recommended making the information in the educational environment more concrete through models or computer animation because his research found that science students (teacher candidates) have some misunderstanding of the classification and interaction of birds. If students cannot access or see accurate concepts, they cannot learn from implementation and experience. Kubiatko and Prokop (2009) discovered that elementary and lower-secondary school students have misconceptions of mammals, and these began in the preschool years when parents had to read stories to their children. Finally, Kubiatko and Prokop (2009) suggested using more visual aids in the teaching process because the visual part of the teaching process is crucial.

Three-Tier Diagnostic Tests

Students are often reluctant to write comprehensive and detailed explanations in their response to open-ended questions (Gurel et al., 2015). Today, many researchers use two-tier (Treagust, 2007) or three-tier (Peşman & Eryılmaz, 2010) tests as scientific concept diagnostic tools. The first-tier measures students' detailed knowledge, and the second tier probes the reason for their choice of item in the first tier (Tsai & Chou, 2002). Duncan and Johnstone (1973) noted that the traditional multiple-choice test cannot reveal the reasoning students used to arrive at an answer. Moreover, students can give a correct answer with a wrong reason (false positive) or a wrong answer with a correct reason (false negative). Furthermore, multiple-choice tests do not diagnose the student's reasons for holding false conceptions (Kirbulut & Geban, 2014).

Griffard and Wandersee (2001) pointed out the two-tier test can deal with the flaws of the answer clue. A three-tier diagnostic test can assist teachers in analyzing their students' reasoning without the need for interviews. This does not only distinguish alternative conceptions from lack of knowledge but also determines the percentages of false positives and false negatives. In conclusion, three-tier diagnostic tests can efficiently assess large samples of students (Peşman & Eryilmaz, 2010).

Three-tier testing has been applied in areas such as astronomy (Korur, 2015), climate change (Karpudewan et al., 2015), and electric circuits (Peşman & Eryılmaz, 2010). Oberoi (2017) developed a test, but it did not elaborate on or discuss the alternative concepts the students had about ecosystems. Considering the above literature and based on the three stages of developing diagnostic tests proposed by Treagust (2007) and Peşman and Eryılmaz (2010), a TDIEC of the ecosystem concept was developed and implemented to learn what alternative conceptions lower-secondary school students have of ecosystems.

Research Methodology

Procedures

A TDIEC of the ecosystem concept was developed to assess ninth-grade students' alternative conceptions of the ecosystem in a Biology course. Responses to the TDIEC were analyzed using quantitative methods. In this study, TDIEC was developed based on the methods of Peşman and Eryilmaz (2010) and Treagust (2007). The test development and implementation procedure consisted of three main phases: (1) conducting interviews and a literature review; (2) constructing and administering a concept map; and (3) developing and administering the TDIEC.

In the first phase, the scope and the list of objectives were determined by three lower-secondary school biology

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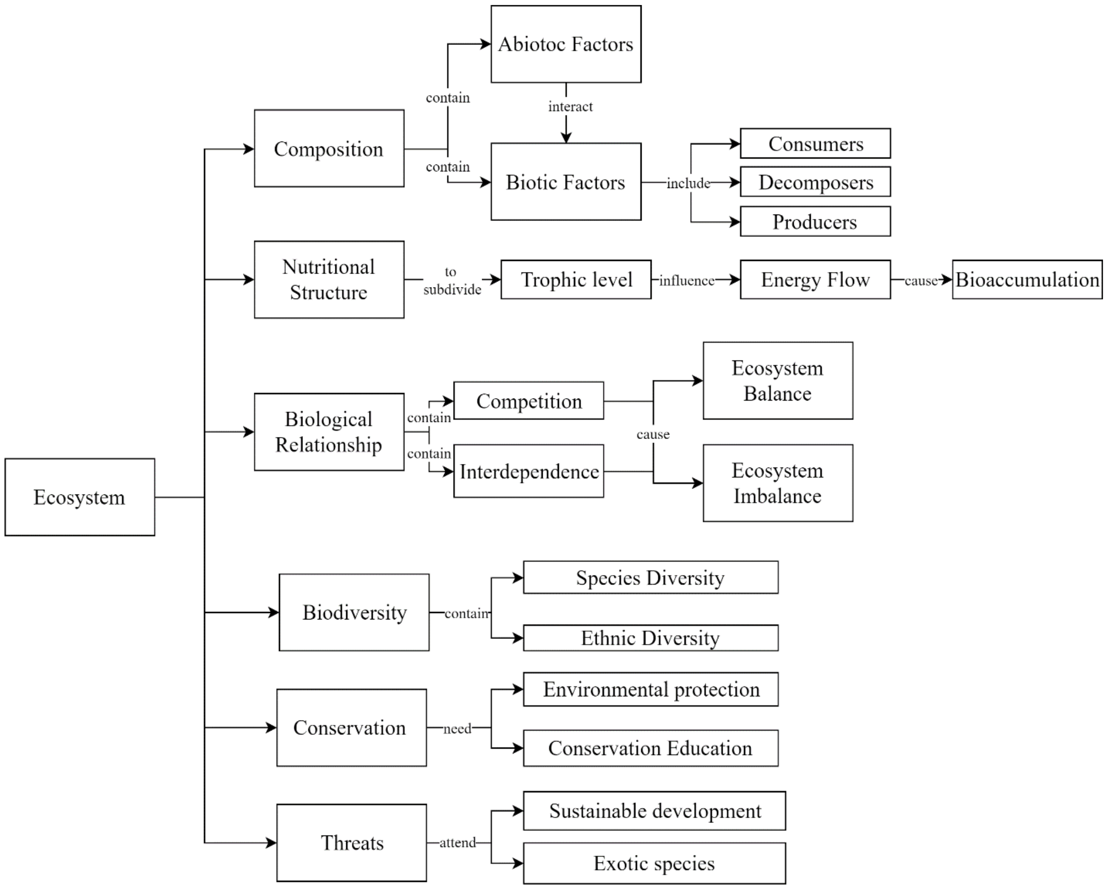
teachers and one professor of Biology from a normal (education) university. The objectives included energy flow and transformation in ecosystems, ecosystem composition, and interaction between organisms. Moreover, students' alternative conceptions were identified by examining the related literature. In the second phase, the contents of the relevant teaching materials in the lower-secondary school ecosystem unit were analyzed, and the main concept map was developed. Figure 1 shows the concept map.

Figure 1
Ecosystem Concept Map



The content boundaries of the concept map were defined based on the Biology curriculum and textbooks with a list of objectives. Propositional knowledge was correlated with the conceptual map to ensure consistency of the content.

Lastly, classification from the concept map and narratives were given as options. These options included one correct option and alternative conception option. Hence, 22 three-tier items were developed. Ninth-grade students completed the TDIEC during the 45-minute class. The research data were collected in November to December 2019. Table 1 summarizes all the items.

Table 1
Propositional Knowledge Statements

CID	concept	Content narrative	Item
Composition and characteristics of Ecosystems			
A1	Elements of an Ecosystem	An ecosystem consists of interdependent and interacting components, such as plants and animals, and non-living elements.	Q1

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CID	concept	Content narrative	Item
A2	Ethnic Group	All the organisms of the same group or special one live in a particular geographical area.	Q2
A3	Community composition	The organisms in the ecosystem are classified as producers, consumers, and decomposers.	Q3
A4	Producers	A producer is an organism that produces complex organic compounds from pure substances present in its surroundings, generally using energy from light or inorganic chemical reactions.	Q5
A5	Consumer	Consumers in ecosystems are living creatures that prey on organisms from a different population; they are organisms that obtain energy from other living things.	Q6
A6	Decomposers	Decomposers can directly absorb nutrients through chemical and biological processes, hence breaking down matter without ingesting it.	Q7
Biological relationship			
B1	Interdependence	Organisms within an ecosystem depend upon each other in order to survive.	Q8
B2	Competition	Competition is an interaction between organisms or species in which both the organisms or species are harmed.	Q4
B3	Ecosystem balance	Ecosystem balance refers to the interrelationships among organisms, including the ability of ecological systems to sustain themselves over time. Balance is a dynamic characteristic rather than a fixed state.	Q9
B4	Ecosystem imbalance	Ecosystem imbalance takes place when a natural or human-caused disturbance disrupts the natural balance of an ecosystem.	Q10
B5	Population growth curve	A growth curve is an empirical model of the evolution of a quantity over time.	Q21
B6	Interspecific relationship	The interspecific relationships are the relationships that show the interactions between the organisms belonging to different species.	Q22
Nutritional structure			
C1	Trophic level	The trophic level of an organism is the position it occupies in a food chain.	Q12
C2	Energy Flow	Energy flow refers to the flow of energy through a food chain; the energy is passed on from one trophic level to the next trophic level, during which about 90% of the energy is lost.	Q13
C3	Bioaccumulation	Bioaccumulation is the gradual accumulation of or the increase in substances, such as pesticides, or other chemicals in an organism. (Alexander, 1999).	Q14
Biological diversity			
D1	Biodiversity	Tropical rainforests exhibit a vast diversity in plant and animal species.	Q11
D2	Species Diversity	Different species of organisms have different ecological niches.	Q16
D3	Ethnic Diversity	Greater population diversity leads to the more excellent stability of biocoenosis in ecosystems.	Q17
Environmental resource conservation, threats to biodiversity			
E1	Environmental protection	Living environment and non-living elements are also essential parts of ecological conservation.	Q15
E2	Conservation Education	Ecosystem conservation is not just the work of professionals. People from all walks of life and industries must participate.	Q18
E3	Sustainable development	Sustainable development refers to a development model that meets the needs of contemporary people under the conditions of protecting the environment and is forward-looking without damaging the needs of future generations.	Q19
E4	Exotic species	The introduction of exotic species often leads to irreversible ecological catastrophes.	Q20

Participants

A pilot experiment was conducted before the main experiment, and an analysis of its reliability was performed. In the pilot experiment, the TDIEC was administered to 38 ninth-grade Taiwanese lower-secondary school students (19 males and 19 females) after they were taught about ecosystems. In the main experiment, the same procedure was done to 106 ninth-grade Taiwanese lower-secondary school students consisting of 51 males and 55 females.

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Instruments

From the previous literature, a preliminary TDIEC of the ecosystem concept was developed. The TDIEC is composed of 22 three-tier items used to assess lower-secondary school students' understanding of ecosystem concepts. The first tier is the conventional multiple-choice step, the second tier is the possible reasons for choosing the answer in the first tier, and the third tier is the confidence level for the answer and reasons. In order to check the content validity of the three-tier test, one professor of Biology from a university of teacher education and three lower-secondary school Biology teachers analyzed the test in terms of consistencies within the first and second tiers.

Data Analysis

The TDIEC scores of students were analyzed using SPSS. There were seven variables: (i) one-tier scores; (ii) two-tier scores; (iii) first two-tier scores; (iv) confidence tiers; (v) false positives; (vi) false negatives; and (vii) alternative conceptions. The variables were written in the columns, and students' unique identifiers were written in the rows of the SPSS data sheet. In addition, false positives and false negatives were determined by looking at all three tiers. It is "false positive" if a student who was confident about the responses given in the first two tiers gave a correct response to the first tier but incorrect reasoning in the second tier. It was coded as 1; otherwise, it was 0. It is "false negative" if a student who was confident about the responses to the first two tiers gave an incorrect response to the first tier but correct reasoning in the second tier. This was coded as 1; otherwise, it was 0. Furthermore, the correlation between the two-tier scores and the confidence tier was checked for the validity of the TDIEC. The overall responses to the TDIEC are divided into five categories: scientific knowledge, alternative conceptions, false positives/negatives, lucky guess, and lack of knowledge (Table 2).

Table 2
All Response Possibilities (Arslan et al., 2012)

First tier	Second tier	Third tier	
		Certain	Uncertain
Correct	Correct	Scientific knowledge	Lucky Guess Lack of Confidence
	Incorrect	Alternative Conceptions (False Positive)	Lack of knowledge
Incorrect	Correct	Alternative Conceptions (False Negatives)	Lack of knowledge
	Incorrect	Alternative Conceptions	Lack of knowledge

Research Results

In the pilot experiment, Cronbach's alpha reliability coefficients of the TDIEC were estimated to be .755, .775, and .979 for the one-tier scores, the two-tier scores, and the three-tier scores, respectively. Table 3 shows the descriptive statistics of TDIEC for the three-tier scores. Item difficulty analysis of the pilot experiment shows three items with a difficulty index of less than 0.20, which categorized them as difficult tasks. All the remaining tasks were in the range of 0.20 to 0.80, which are tasks of moderate difficulty. Discrimination indices of the pilot experiment ranged from 0.22 to 0.75. A value of 0.22 was established as a minimum, and those with 0.20 were considered acceptable without the need for further revision of the test items. These results indicate TDIEC allows the contents of the test questions to reflect the ecosystem curriculum in lower-secondary school, and the test items also show how students form alternative conceptions.

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Table 3
Descriptive Statistics of the TDIEC for Three-Tier Scores

	n		*M*	*SD*
Number of items	22			
Number of participants	38			
Mean	12.25			
Standard deviation	4.336			
Minimum	4			
Maximum	19			
Skewness	-.521			
Kurtosis	-.298			
Cronbach alpha		.829		
Difficulty indices			.56	.28
n of items (range 0.60-0.79)	4			
n of items (range 0.40-0.59)	12			
n of items (range 0.20-0.39)	3			
n of items (range <0.20)	3			
Discrimination indices			.49	.17
n of items (range 0.80-1.00)	0			
n of items (range 0.60-0.79)	5			
n of items (range 0.40-0.59)	10			
n of items (range 0.20-0 .39)	7			

Table 4 summarizes the overall descriptive statistics of the correct and misconception scores in the main experiments. The means and standard deviations for TDIEC (M = 8.94, SD = 5.121) and difficulty indices of the TDIEC (M = 0.41, SD = 0.20) range from 0.18 to 0.78, providing a wide range of difficulty items. This is closely related to the item difficulties of the main experiment. Being an alternative conceptions diagnostic test, the TDIEC has very strong detractors. This is the primary reason why most of the items are tricky. The discrimination indices of the main experiment (M = 0.61, SD = 0.17) range from 0.22 to 0.81.

Table 4
Descriptive Statistics of the TDIEC for the Three-Tier Scores

	n		*M*	*SD*
Number of items	22			
Number of participants	106			
Mean	8.94			
Standard deviation	5.121			
Minimum	0			
Maximum	20			
Skewness	-.049			
Kurtosis	-1.204			
Cronbach alpha		.870		
Difficulty indices			.41	.20

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	n	*M*	*SD*
n of items (range 0.60-0.79)	4		
n of items (range 0.40-0.59)	8		
n of items (range 0.20-0.39)	6		
n of items (range <0.20)	4		
Discrimination indices		.61	.17
n of items (range 0.80-1.00)	2		
n of items (range 0.60-0.79)	12		
n of items (range 0.40-0.59)	5		
n of items (range 0.20-0.39)	3		

The percentage of confident students who had false positives, false negatives, and alternative conceptions were calculated. Table 5 summarizes these results. When the items were checked for false positives and false negatives, the two items were less than 10, with averages of 3.64 and 3.51, respectively. In terms of alternative conception values, all values were high, with an average of 6.56. Alternative conceptions are considered significant when they exist in at least 10% of the sample (Caleon & Subramaniam, 2010). According to Table 5, there are items with a high percentage of alternative conceptions in the TDIEC (e.g., Item 3, Item 4, Item 7, and Item 21). This result supports the use of three-tier tests rather than traditional multiple-choice tests. Alternative conceptions and lack of knowledge can be distinguished by three-tier tests, and students' alternative conceptions are subject to more accurate analyses. The disadvantages of traditional or two-tier tests are improved by three-tier tests. Traditional or two-tier tests overestimate alternative conceptions because lack of knowledge is evaluated as an alternative conception.

Table 5
Percentages of False Negatives, False Positives and Alternative Conceptions

Items	False Positives	False Negatives	Alternative Conceptions
Item 1	1.88	2.83	5.66
Item 2	4.71	12.26	7.54
Item 3	1.88	0.00	13.20
Item 4	0.00	1.88	15.09
Item 5	3.77	10.37	3.77
Item 6	1.88	0.94	6.60
Item 7	13.20	1.88	10.37
Item 8	0.00	2.83	1.88
Item 9	4.71	6.60	7.54
Item 10	0.94	0.00	1.88
Item 11	2.83	1.88	7.54
Item 12	3.77	0.00	4.71
Item 13	0.94	2.83	7.54
Item 14	2.83	1.88	6.60
Item 15	6.60	1.88	5.66
Item 16	1.88	4.71	4.71
Item 17	0.94	2.83	3.77
Item 18	6.60	0.00	6.60
Item 19	3.77	7.54	6.60

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Items	False Positives	False Negatives	Alternative Conceptions
Item 20	3.77	4.71	1.88
Item 21	10.37	0.94	10.37
Item 22	2.83	8.49	4.71
Mean	3.64	3.51	6.56
Standard deviation	3.23	3.48	3.40

The percentage of correct responses of students who completed the TDIEC, as shown in Table 6, are as follows: the first-tier average correct answer rate is 52.87%, the first tier and second tier (both tiers) average answer rate is 52.18%, and the first tier, second tier and third tier (all three tiers) have an average answer rate of 40.65%. If we compare the average values of achievement shown in Table 6, achievement gradually decreases as the number of tiers increases.

Table 6
Percentages of the Lower-Secondary School Students' Responses (unit: %)

Items	Correct responses			Lack of Knowledge	Certainty
	One tier	Two-tier	Three-tier		
Item 1	22.64	23.58	17.92	71.70	33.01
Item 2	32.08	61.32	25.47	32.07	34.90
Item 3	29.25	27.36	25.47	68.86	27.35
Item 4	47.17	41.51	38.68	50.00	33.96
Item 5	57.55	71.70	50.00	20.75	34.90
Item 6	66.04	63.21	55.66	26.41	34.90
Item 7	21.70	14.15	1.88	66.03	27.35
Item 8	82.07	76.41	68.86	10.37	44.33
Item 9	23.58	27.35	11.32	60.37	25.47
Item 10	83.96	82.07	78.30	12.26	40.56
Item 11	52.83	50.94	41.50	37.73	27.35
Item 12	69.81	56.60	51.88	25.47	32.07
Item 13	61.32	58.49	48.11	28.30	27.35
Item 14	75.47	67.92	63.20	19.81	45.28
Item 15	73.58	56.60	50.94	20.75	34.90
Item 16	49.05	65.09	37.73	23.58	21.69
Item 17	64.15	69.81	55.66	21.69	22.64
Item 18	59.43	45.28	43.39	38.67	29.24
Item 19	39.62	52.83	28.30	35.84	30.18
Item 20	69.81	69.81	62.26	22.64	37.73
Item 21	39.62	11.32	1.88	50.94	22.64
Item 22	42.45	54.71	35.84	38.67	31.13
Mean	52.87	52.18	40.65	35.59	31.77

Palander (2001) pointed out that when the number of samples exceeds 100, the construct validity is independent of the Pearson correlation coefficient and is closely related to statistical significan ce. Therefore, the relationship between two-tier scores and confidence tiers was tested using the Pearson product-moment correlation coefficient. Evaluation of the correlation between the second-tier score and the third-tier response as construct validity shows a significant

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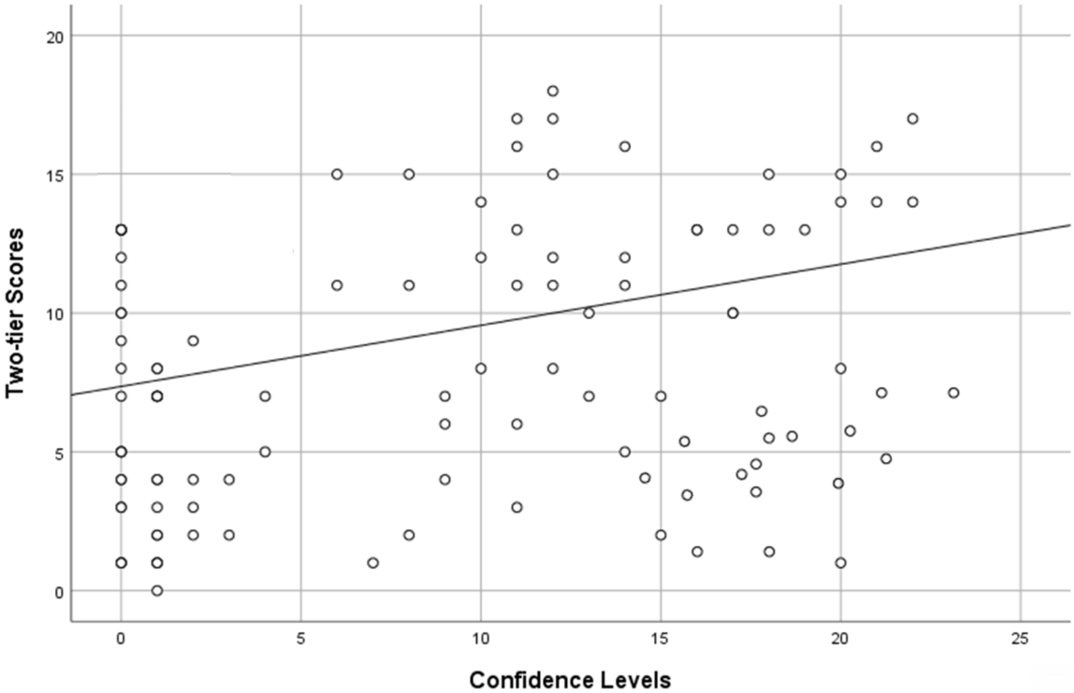
positive correlation (r = .314, n = 106, p < .001), with high scores in the third tier having a high level of confidence (see Figure 2). The lower-secondary school students who scored higher in the test were more confident than students with lower scores. Figure 2 shows that some students with high confidence level scored low, which indicates that these students are pretty confident about their responses to the test and probably have alternative conceptions about ecosystems.

Figure 2
Scattered Diagram of Scores vs. Confidence Levels



The TDIEC diagnosis found that the number of alternative conceptions in each of the 22 items discussed in this study ranged from 0 to 20 (average of 3.20 per subject for alternative conceptions). Table7 summarizes these results.

Table 7
Number and Percentage of the Students' Alternative Conceptions

Number of Alternative Conceptions	0	1	2	3	4	5	6	7	8	9	10	12	13	19	20
Number of Student	32	24	9	3	4	8	6	6	5	3	1	1	2	1	1
Percentage	30.2	22.6	8.6	2.8	3.8	7.5	5.7	5.7	4.7	2.8	0.9	0.9	1.9	0.9	0.9

Discussion

In this study, a TDIEC of the ecosystem concept was developed based on the three stages of diagnostic tests proposed by Treagust (2007) and Peşman and Eryılmaz (2010). The three-tier diagnostic paper-pen test was administered to Taiwanese lower-secondary school students to gain a deeper understanding of their current ecosystem concepts and learn what alternative conceptions they have of ecosystems.

The items that more than 10% of confident students selected suggest common alternative conceptions related to this knowledge. These items and the percentage of students who showed their lack of knowledge are in Appendix A.

In Item 2, students were required to explain and distinguish the conditions that make up the ethnic group. In

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order to successfully answer this item, students had to know that ethnic groups are composed of individuals of the same race at the same time and in the same environment and understand which ones can be defined as the same race. A total of 12.26% of confident students wrongly concluded that different species of birds or tropical fish can be classified as the same species (AC1). The reason for this may be because existing courses and textbooks are reductionist in their conceptualization of subject knowledge. In addition, the content of the course and the textbook does not particularly distinguish organisms in detail. Eventually, students wrongly concluded that they could classify animals of different species but of the same family or the same order into the same species. Le, et al. (2018) found that lower-secondary school students face real obstacles when classifying even most known animals (geese, butterflies, crocodiles, etc.). These obstacles are often misconceptions and are poorly treated and reformulated in the teaching-learning process. Many students used "non-taxonomic" criteria, such as habitat and locomotion to classify animals even after learning the categories of the biological taxonomy. In addition, their study found that lower-secondary school students have almost the same alternative conceptions of animal classification as senior high school students.

The second alternative conception is a common one. Although the Venus flytrap and nepenthes "capture " and digest insects and small animals, the main result is the absorption of mineral nutrients, particularly nitrogen, rather than energy transfer (Hershey, 1999). Therefore, carnivorous plants are not included in food chains as carnivores. In the existing courses and textbooks, the concept of food chains is often summarized as obtaining energy through eating habits. Therefore, 13.20% of confident students wrongly concluded that when the Venus flytrap and nepenthes "capture" and digest insects and small animals, they can get the energy necessary for survival from insects.

In Item 4, students were required to distinguish between competition and predation. In order to answer this correctly, students had to know that competition exists when two kinds of living things live in the same environment. Because the required resources are similar, they compete with each other for resources and space. Predation refers to one organism preying on another organism as food. However, 15.09% of confident students wrongly assumed that predation is a competitive interaction (AC3). The reason for this inference may be because ambushing, hunting, hiding, and killing in predation are often defined as competition in daily life.

In Item 5, students were required to understand the diversity of nutritional modes in plants. To do this well, students had to know that not every plant is an autotroph as some depend on others for food, making them heterotrophs. A total of 10.37% of confident students wrongly answered that those plants absorb energy through the absorption of insects (AC4). Although fewer students gave wrong answers (20.75%), these students had high confidence in their wrong answers. The reason is similar to AC2: The explanation of the food chain concept in the classroom causes students to misunderstand.

In Item 7, students were required to distinguish conceptual differences between decomposers and scavengers. For them to choose the correct answer, they had to know that a scavenger is an animal that feeds on dead plants, animals, or carrion. It can also be called a detritivore since a scavenger relies on waste materials. In addition, a decomposer is a soil bacterium, fungus, or invertebrate that decomposes organic material. It can also be called a saprotroph, which recycles dead plants and animals into nutrients (Rachna, 2020). Their difference is the way the material circulates, as the scavenger converts inorganic matter into organic matter, and the decomposer converts organic matter into inorganic matter. A total of 13.20% of confident students wrongly inferred that vultures, dung beetles, and maggots are decomposers (AC5) because students confuse decomposers with scavengers (vultures, dung beetles, maggots, etc.), Özkan et al. (2004) determined that seventh-grade students have misconceptions of decomposers, as they assumed that decomposers eat dead plants and animals to keep the environment clean.

The AC6 alternative conception occurs in the same item as AC5. Although some students can recognize that mushrooms are decomposers, teachers often use rotten trees as lecture cases, making 10.37% of confident student substitute the concept of saprophagous for the saprophytic decomposers. Because these concepts are similar, it is easy for students to confuse them, and students are also mixed up between ingestion and decomposition. Butler et al. (2015) noted that 20.86% of upper secondary students misunderstood that decomposers are classified as predators as they obtain their food from dead plants and animals.

Scientific interpretation relies on the clear presentation of data (Menge et al., 2018). In Item 21, students were required to differentiate interaction which results in the changes in the population of ethnic groups. In order to successfully answer this item, students had to be fully aware that the predator–prey relationship exhibits periodic fluctuations in population according to the Lotka-Volterra equation (Lotka, 1926). The graph presented by Item 21 is a typical example used in textbooks and examinations. A total of 40% of students understood the relationship represented by the graph. However, they easily misunderstood and found it challenging to analyze the principles of the detailed process of the changes in the graph (AC7 and AC8). When students are confronted by prey–predator interactions, their most

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common response is to assume a linear, uni-directional relationship between prey and predator populations (Booth et al., 2007). In addition, Hovardas (2016) pointed out that learners' misconceptions and learning difficulties related to linear thinking persist after instruction. Even pre-service teachers and educators present inefficient non-linear reasoning (Eilam, 2012). This often results in oversimplifying the structure and dynamics in ecological systems (White, 2008). Moreover, most of the visuals included in Biology textbooks are post hoc, or after the fact, and graphics rarely include predictive relationships (Brooks, 2013).

By using the percentages of lack of knowledge, teachers can evaluate their content, materials, and methodology of instruction. A large percentage of lack of knowledge may mean that the instruction did not facilitate students' understanding of the related concepts. This study aggregates more than 60% of the lack of knowledge in Appendix B. This study also found that the highest percentage of lack of knowledge (71.70%) occurred when students assumed that only biological factors constitute an ecosystem, even though biological textbooks clearly and directly indicate that an ecosystem is composed of both biological and abiotic factors (Shih, 2018; Wu, 2019). However, the existing Biology curriculum is too focused on teaching and discussing biological factors, especially the concepts and interactions of producers, consumers, and decomposers. Brooks (2013) observed that Biology textbooks may sometimes neglect to incorporate living and non-living elements into the graphics. The second-highest percentage of lack of knowledge (68.66%) was found when students wrongly assumed that carnivorous plants are not producers. Students believed that carnivorous plants capture and digest insects and small animals to get the energy necessary for survival. The reason may be because the concept of the food chain is often summarized as obtaining energy through eating habits.

The third-highest percentage of lack of knowledge (66.03%) was noted when students wrongly answered that vultures, dung beetles, and maggots are decomposers. Students cannot distinguish decomposition from ingestion because these concepts are abstract and similar. The fourth-highest percentage of lack of knowledge (60.37%) was due to students' not understanding that ecological balance does not mean that no disturbance ever occurs. An ecosystem will typically recover to a balanced state after a disturbance occurs. A total of 22.60% of the students wrongly inferred that ecological balance refers to a fixed number of plants and animals, and the formation of sustainable consumption and production. The reason could be the students' application of their knowledge of stable equilibrium state in Physics in the context of ecosystem. The study also found that 44.30% of students thought that the energy of the ecosystem could reach a permanent cycle. Students may mistakenly relate the concept of the Law of Conservation of Energy in Thermodynamics to ecological concepts.

Conclusions

The results of this study show that the TDIEC has moderate difficulty, but it is a valid and reliable tool for identifying alternative conceptions and students' understanding with a high level of certainty.

The vast majority of the graphics used in biology textbooks are either directly or indirectly reductionist. As textbook authors address problems by appealing simultaneously to holistic and reductionist ideas, this sometimes leads to meaningless and confusing depictions of ecosystems and may result in readers' forming severe misconceptions.

This study also shows that the average ratio of students correctly completing the TDIEC is 40%. Moreover, the students generally had a high ratio of alternative conceptions. These results reveal a need for strengthening students' concepts of ecosystems. Therefore, Biology textbook authors and illustrators should enhance descriptions of common ecosystem alternative conceptions in order to help students address these fallacies.

Three-tier tests provide opportunities for teachers to gain deeper insights of students' knowledge and understanding of ecosystems, some of which are contrary to scientific facts. These findings enrich the literature in this area. In addition, the TDIEC can be used as a pre- and post-test to assess students' knowledge and misconceptions of the subject matter.

Declaration of Interest

The authors declare no competing interest.

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Appendix A

Consistent Alternative Conceptions of Grade 9 Students

ID	Alternative Conceptions	Item	Percentage
AC1	Different species of organisms could be classified as the same species.	Item 2	12.26
AC2	Carnivorous plants are decomposers or consumers.	Item 3	13.20
AC3	Predation is also a competitive interaction.	Item 4	15.09
AC4	Carnivorous plants absorb energy through the absorption of insects.	Item 5	10.37
AC5	Vultures, dung beetles, and maggots are decomposers.	Item 7	13.20
AC6	Students substitute the concept of saprophagous for the saprophytic decomposers.	Item 7	10.37
AC7	The prey-predator system has a temporal dimension, where populations present continuous oscillations.	Item 21	10.37
AC8	There is a correlation between changes in species numbers and relationships.	Item 21	10.37

Appendix B

Highest Percentage of Lack of Knowledge

Lack of Knowledge	Item	Percentage
Students believe that LK1: Only biological factors constitute an ecosystem, ignoring abiotic factors.	Item 1	71.70
LK2: Venus flytrap and nepenthes are consumers or decomposers.	Item 3	68.66
LK3: Vultures, dung beetles, and maggots are decomposers because they eat corpses or excreta to gain energy.	Item 7	66.03
LK4: Balance in nature is determined by the resources in the ecosystem to achieve continuous production and consumption as well as constant circulation.	Item 9	60.37

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