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ORIGINAL ARTICLE

Developing and Assessing Learning Progression for Botanical Literacy Using Rasch Analysis

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ABSTRACT

This study aimed to develop a learning progression (LP) for botanical literacy and assess the impact of a garden-based education course on Thai pre-service science teachers (n = 49). The inquiry- and community-based education course was taught over a 15-week period. To measure botanical literacy, a 50-item multiple-choice test was employed. A hypothetical model of the construct was proposed and validated using a dichotomous Rasch model. Results indicated that the model fits the data well. Thus, the hypothetical model was confirmed. The validated botanical literacy comprised conceptual and procedural domains. Each domain had several core ideas and subordinate concepts located on a linear construct and arranged by increasing difficulty. For example, in the conceptual domain, the core ideas arranged from the easiest to most difficult were plant diversity, plant morphology, and plant eco-physiology. The botanical literacy of the pre-service teachers was measured before and after the instruction. To measure the learning gain, we fixed the pre- and post-item difficulty and estimated the post-instruction person ability. The means of pre- and post-instruction person ability were compared using the Welch t-test. We found that learning gain was statistically significant ($p < 0.01$). This study discusses implications of LP for botanical literacy in biology education.

KEYWORDS: botanical literacy; learning gain; pre-service teacher; rasch model

INTRODUCTION

Public interest in plants and nature is rising. Consequently, the public is exposed constantly to plant terminologies in media, such as genetically modified crops and integrated pest management, and is sometimes required to make decisions on such issues. The ability to know and understand plant terminology, explain natural phenomena about plants, engage in conversation, and make personal decisions about socioscientific issues related to plants is called botanical literacy (Uno, 1994). The concept of botanical literacy is consistent with better known, broader concepts of biological and scientific literacy (Uno and Bybee, 1994). Despite the significance of botanical literacy in modern society, thus far, we know little about its construct. Most national and international surveys such as TIMSS and PISA focus on achievements or scientific literacy. However, these high-stake tests were designed to cover a wide range of science content, resulting in limited content specificity. This deficiency points to the need for developing and validating the construct of botanical literacy and developing a new standardized instrument to measure it, a process known as learning progression (LP). We can use such a high-quality assessment tool to survey or examine the impact of school science experience on the botanical literacy in high school students or examine the effect of teacher preparation courses on the learning gain of pre-service teachers in this essential construct, as in the case of this study. This study measured the learning gain in botanical literacy among pre-service science teachers who had participated in a garden-based education course designed to equip them with basic botanical concepts, pedagogical knowledge and teaching techniques, and field trip management. In short, the scope of this study was an attempt to validate the botanical literacy construct and examine the effect of the garden-based education course on the botanical literacy of participants.

Research Objectives

This study aimed to:

1. Validate a LP for botanical literacy using Rasch analysis and
2. Examine the impact of an inquiry- and community-based gardening education course on the botanical literacy of pre-service science teachers.

LITERATURE REVIEW

Garden-based Education

Connecting with nature determines people's worldview and behavior (Bateson, 1979; Rees, 2002; Walker et al., 2004). A disconnection with nature is claimed to be a main cause of environmental deterioration (Suzuki and McConnell, 2007). Botanical gardens are some of the places where this connection

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is made by the public. They can provide an environment that helps people reconnect with nature by providing information on the living plant collections they sustain, enhancing nature appreciation, and raising awareness about the conservation of local plant biodiversity (Ryken, 2009).

In education, school botanical gardens (SBGs) can provide a living learning resource for sustainability in a school context in various subjects, such as science, agriculture, environmental science, and extracurricular activities. Cutter-Mackenzie (2009) suggested that gardens have the potential to influence positively the linguistic, cultural, and environmental knowledge of children through gardening activities. Ultimately, they can involve communities in conservation and sustainability issues (Wyse Jackson and Sutherland, 2000). Blair (2009) and Ohly et al. (2016) conducted systematic reviews on the short- and long-term impact of garden-based education and found that gardens can provide opportunities for children to learn about science, art and expression, literacy, health and nutrition, and the environment. Dyment and Bell (2008) studied the effect of school "greening" in urban elementary and secondary schools in Ontario, Canada. Many of the schools in their study were in low socioeconomic populations with high racial diversity and different first languages. The authors found that garden-based learning contributed to an inclusive education by welcoming differences, such as intellectual disabilities. The current research was motivated by such literature. Overall, Sanders (2007), *Ohly* et al. *(2016)*, and *Murakami* et al. (2018) suggested that SBGs remain under-researched in terms of teachers' teaching and learning process, conceptual understanding, and teaching practice in this informal learning environment.

LP

Duschl et al. (2007) defined LPs as "descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time" (p. 219). Similarly, Smith et al. (2006) defined LPs as empirically validated descriptions of successively more sophisticated ways of understanding scientific concepts. It is worth noting that LP research differs from misconceptions (or alternative conceptions) research in that it looks at students' ways of approaching a broad set of ideas rather than their understanding of a specific concept. They represent a promising framework for developing organized curricula and meaningful assessments in science. Well-grounded LPs allow for coherence between science curriculum standards, classroom instruction, and assessments (Wilson and Sloane, 2000). LPs may ultimately provide the detail needed for teachers to track student thinking over the course of instructional units. For these reasons, LPs are rapidly gaining popularity in the science education research community (Liu and Jackson, 2019).

In this study, LPs were conducted under the framework of modern test theory (MTT), known as item response theory (IRT), technically often using Rasch analysis. The Berkeley Education Assessment Research (BEAR) group has led the research on linking assessments to LPs and developed the BEAR Assessment System (Wilson, 2005; 2009; Wilson and Sloane, 2000) used for developing validated assessments tied to LPs.

According to BEAR, an LP initially is a hypothetical linear model, guided by a literature review and national standards. Corcoran et al. (2009) arranged various ideas or components of a learning outcome to reflect students' thinking within a specific domain, which contains upper and lower bounds, and identify varying levels of learning performances from the easiest to most difficult. This conceptualization is called a construct map. Note that LPs at this stage are typically logical rather than evidence-driven processes. Sets of items are then developed to measure the students' levels on the progression. Data obtained from administering these items to students are used to estimate item difficulty and person ability parameters and examine whether the data fit with a measurement model of IRT. LPs may comprise more fine-grained descriptions of student thinking – over either a smaller span of time or a smaller slice of content – such that a broad LP may consist of a number of smaller progressions like in the case of the botanical literacy discussed below. However, the larger the scope of an LP, the less feasible it may be to provide detailed descriptions of student thinking. Validated LPs can inform not only item revision but also the consideration of the LP itself. They are usually validated through multiple rounds of empirical testing (Rogat et al., 2011; Shea and Duncan, 2012). In other words, the development of an LP is necessarily an iterative process. Progression-based assessments can be used to help teachers understand and respond effectively to students' ideas in the classroom (Furtak, 2009; Furtak et al., 2012). They also guide future instructional paths considering the level of knowledge the students have (Mohan and Anderson, 2009) and provide a link between instruction, assessment, and national standards, thereby creating an interdependent assessment system (Wilson, 2009). For these reasons, LPs are rapidly gaining popularity in the science education community.

In the present study, we adopted the BEAR assessment system to develop a high-quality instrument to measure the construct of botanical literacy and validate a LP for botanical literacy. A cycle of a 4-step process of BEAR was conducted. First, building a construct map; a hypothetical linear construct of learning an outcome of interest was proposed. Conceptually, it is a string of key concepts of plants that progress from simplest at one end to the hardest at the other end. The construct map was guided by the literature review on students' ideas about plants and the framework of the structure of observed learning outcomes (SOLO) taxonomy (Biggs and Collis, 1982). Second, we designed and developed an instrument to measure each target concept in a construct map. Third, depending on the format of the instruments, outcome space was identified. In our study, we used a multiple-choice test, so the outcome space for this test format was dichotomous. Forth, we tested and validated the construct map with the empirical data applying

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Rasch model. The findings would reveal validate a LP for botanical literacy.

Procedure

Intervention

The second author taught a gardening education course to 49 pre-service science teachers. To participate in the present study, we asked for their consent and the participation was entirely based on voluntary basis. The student teachers enrolled at a university located in the southern part of Thailand. Most of the student teachers were Buddhists with a smaller minority as Muslims. They came from middle-income families. Their parents generally were farmers. The gardening education course was an elective course in Bachelor of Education (B.Ed.) in general science program. This 15-week experiential and inquiry-based course was a compulsory course of the B.Ed. in Science Teaching at a teacher preparation institution in the southern part of Thailand. The course aimed to equip prospective teachers with conceptual and procedural knowledge of basic botany as well as introduce and demonstrate the main learning activities of Thailand's gardening education program, named Botanical Garden in School Program (BGSP) (RSPG, 2017). Most schools in Thailand have been implementing BGSP to promote botanical literacy and environmental awareness to conserve the plant diversity at risk in Thailand. Following the training materials of BGSP, the pre-service teachers were taken into nature and encouraged to sense and appreciate the beauty and wonder of the green world. For instance, they selected a plant study plot, identified the plants in their community, and conducted a guided inquiry to learn the morphology, anatomy, and physiology of the plants. They collaboratively studied the selected plant of interest in great detail to search for and discover a hidden potential that would inspire them to create and invent an innovation for sustainability for the benefit of their locale, the nation, and the world. Their project was supervised by resource persons and intellectuals in their locales.

Development of Botanical Literacy Test

This study adopted the structural level of scientific literacy as a framework for botanical literacy (Uno and Bybee, 1994). At the structural level, students have a conceptual understanding of big ideas and possess procedural knowledge and skills in science, specifically botany in this study. We, therefore, hypothesized the botanical literacy construct comprising conceptual and procedural domains. Each domain consisted of several core ideas, and each core idea had subordinate concepts. With the adoption of a developmental perspective and the structure of observed learning outcomes (SOLO) taxonomy (Biggs and Collis, 1982), as elaborated below, botanical literacy is conceptualized as a linear construct in which core ideas and their corresponding subordinate concepts are ordered by increasing conceptual or task complexity from the least to most difficult. We also hypothesized the concept or task that is more familiar or represented at the macrolevel, which would be easier than those that are unfamiliar or represented at the micro/symbolic/cross level. The structure and organization of botanical literacy are displayed in Table 1 and Figure 1, respectively.

We refer to SOLO taxonomy (Biggs and Collis, 1982) to explain Figure 1. Any learning outcome comes with a different structural complexity from the simplest to the most complicated. Arranged by increasing difficulty, the components of the learning outcome are pre-structural, unistructural, multistructural, relational, and extended abstract. We hypothesized that the conceptual domain should be easier than the procedural domain. In the conceptual domain, we regarded the core idea of plant diversity as the easiest, the core idea of plant eco-physiology as the hardest, and the core idea of plant morphology located between the two core ideas. We considered plant diversity to consist mostly of unistructural concepts, whereas plant eco-physiology consists generally of relational concepts. The latter has many interrelated components in its concept while the former has only a single component. In the procedural domain, we thought that the core idea of planting and nurturing is easier than the core idea of plant identification. We assumed that students had learned planting and nurturing plants from their agriculture subject since the primary level, whereas plant identification was new knowledge for them.

Similar to measuring any variable in social science, botanical literacy cannot be directly observed but inferred from a set of manifest variables. By this sense, it is a latent variable and should be treated as is in an assessment system. We chose

Table 1: Domains, core ideas, and subordinate concepts of botanical literacy

Domain 1: Conceptual knowledge		
Core idea 1: Plant diversity	**Core idea 2: Plant morphology**	**Core idea 3: Plant eco-physiology**
• Knowing plants in their neighborhood • Major groups of plants (non-vascular plants, seedless vascular plants, gymnosperms, angiosperms)	• Structure and function of the external structures of a plant (root, stem, fruit, flower, leaves)	• Factor affecting photosynthesis • Plant responses to heat and drought stresses • Food web • Plant growth and development
Domain 2: Procedural knowledge		
Core idea 4: Plant identification	**Core idea 5: Planting and nurturing a garden**	
• Locating a study site and labeling an unknown plant • Writing a scientific name and constructing a scale map • Distinguishing between tree, shrub, herb, and vine • Collecting and preserving a plant specimen • Recording and interpreting plant data	• Choosing an appropriate soil type for a certain plant • Improving soil quality • Selecting an appropriate seasonal plant • Propagating a plant • Controlling pests	

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matching and multiple-choice tests in consideration of the content coverage and objectivity (Boone and Scantlebury, 2006). There were 50 items. We adopted the Rasch model or one-parameter logistic model, which is an IRT model to validate our hypothetical model (Figure 1). Some big advantages of the IRT of MTT over the classical test theory is that item difficulty and student ability are on a true interval scale, very much like that of scientific instrumentation, and mutually independent (Wilson, 2005). Consequently, the measurement developed using IRT does not need to be revalidated whenever the target sample is different from the original validation sample. The item and test difficulty, in other words, remain invariant. To validate a construct map and examine the impact of the garden-based education course, Rasch analysis was carried out using R software and Test Analysis Module package. To measure learning gain among the participants, we used the stacked approach by fixing the item difficulty of the pre- and post-tests to give the same frame of reference and compare the means of person ability parameters through the Welch t-test.

RESULTS AND DISCUSSION

Fit statistics results indicated that our measurement model fits the empirical data very well. Forty-nine items fell in the acceptable range; the range of mean square infit and outfit is 0.7–1.3 for a teacher-made, multiple-choice test (Wright and Linacre, 1994). The infit of items had the maximum value of 1.14 and the minimum value of 0.87 while the outfit had the maximum value of 1.25 and the minimum value of 0.74. The descriptive statistics of the item difficulty by domain and core idea are shown in Table 2. The average item difficulty of the whole test was −0.37 logits (mean at 0 indicates medium difficulty). The minimum value of the item difficulty was −2.82, and the maximum value was 2.50. The hypothesized relative locations of the item difficulty of the domains and the core ideas on the construct map were confirmed, in that the conceptual domain (−0.27) was more difficult than the procedural domain (−0.51). In the conceptual domain, the item difficulty of the core ideas was aligned with the SOLO taxonomy, in which plant diversity was the easiest core idea (−0.55), followed by plant morphology (−0.21), and then plant eco-physiology (−0.05) as the most difficult one. Regarding the core ideas of procedural domain, plant identification was more difficult than planting and nurturing (−0.24 and −0.79 logits, respectively). This validated model was used as an LP for botanical literacy.

Once item difficulties of the pre-test were fixed, the post-instruction person ability parameters were estimated and compared with those of the pretest. The learning gains were visualized by Wright maps in Figure 2. The distribution of the person ability parameters was shifted to the right after the instruction indicated a positive gain of botanical literacy; in other words, there were more students with higher ability at the end of the instruction. The visual inspection was confirmed by the Welch t-test results. There was a significant increase in person measures at the end of the intervention ($M_2 = 0.42$, $SD_2 = 0.70$) compared to the person measures before the implementation ($M_1 = -0.0016$, $SD_1 = 0.57$), $t(91.69) = -3.29$, $p < 0.01$).

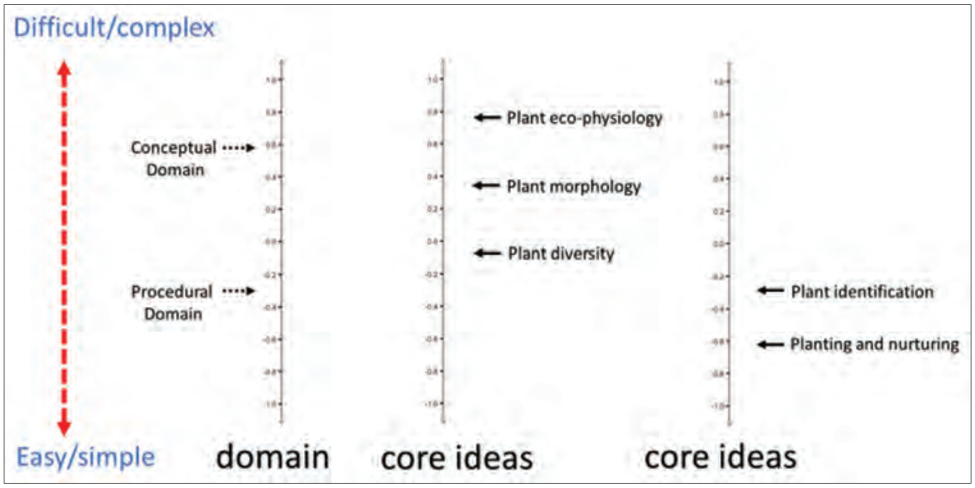

Figure 1: Domains and their core ideas in the hypothetical construct map of botanical literacy

Table 2: Estimated item difficulty of the domains and core ideas measured by botanical literacy test

Domains	Conceptual knowledge (logits)			Procedural knowledge (logits)	
Core ideas	Diversity	Morphology	Eco-physiology	Identification	Planting
Mean	−0.55	−0.21	−0.05	−0.24	−0.79
Standard deviation	1.30	1.13	1.37	0.80	1.15
Minimum	−2.51	−1.70	−1.42	−1.30	−2.82
Maximum	1.18	1.87	2.05	1.07	0.96
Count (items)	10	10	6	14	9

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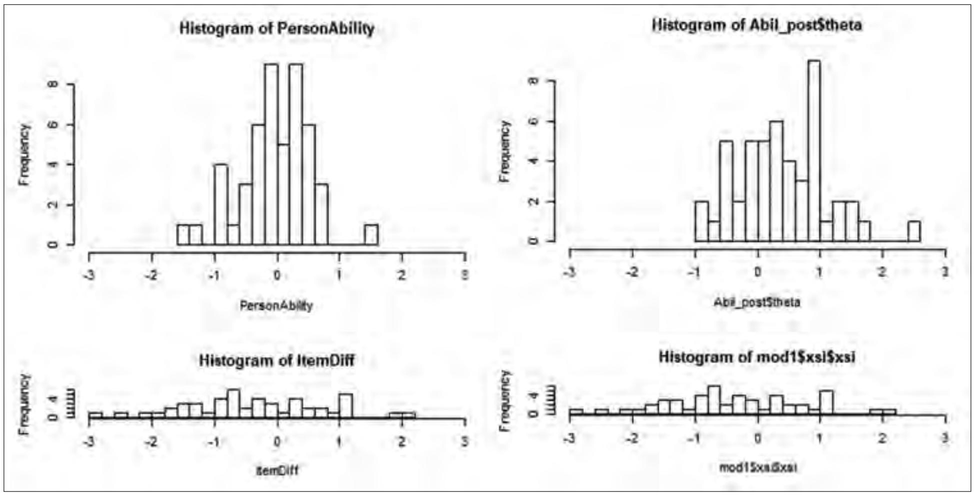

Figure 2: Wright maps of the pre-test (left) and post-test (right) when item parameters were fixed

The findings of this study confirm the idea of verifying LPs extensively in the literature with diverse science content areas and domains of science learning (Duncan and Hmelo-Silver, 2009; Wilson, 2009). We found that botanical literacy could be conceptualized as a linear construct progressing from the least complex (plant diversity items), to more complex (e.g., most plant morphology items), and to the most complex (e.g., most plant eco-physiology items). For example, at the subordinate concept in the core idea of plant diversity, we found that the items using more familiar plants were easier. The other factor was the abstraction of the concept. More abstract concepts, at a microscopic or molecular level, were more difficult to understand for the students even if the two concepts were equivalent in their conceptual complexity, like in the case of the core idea of plant eco-physiology. The influence of familiarity of the context used in a test and the abstraction found in this study was extensively evidenced in the literature (Driver et al., 1994; Johnstone, 1982; 1993)

CONCLUSIONS

In previous research on students' progression on understanding energy, researchers identified a sequence of conceptions related to four key ideas about energy – forms, transfer and transformation, dissipation, and conservation – along which they expected students to progress. This sequence was confirmed in multiple empirical studies (Dawson-Tunik, 2006; Liu and McKeough, 2005; Neumann et al., 2013; Yao et al., 2017). Yao et al. (2017) hypothesized that the four conceptual development levels to the understanding of energy would, in sequence, progress from fact, mapping, relation, and systematic levels. Their hypothesis was confirmed because fact level items are located at the bottom of the Wright map, which means that these items were the easiest, whereas systematic level items are located at the top, indicating these items were the most difficult for students. Mapping and relation level items are ranging in between as expected. These conceptual development levels progressed from the simplest to the most complicated. Our present study was consistent with these studies in that the major concepts in botany progress increasingly by its complexity in a validated construct map: Plant diversity, plant morphology, and plant ecophysiology. When looked at an individual question level, however, we found that the items of a particular major concept were not distinct. There were some items overlaps with those of other adjacent major concepts. This was aligned with Yao et al. (2017) that studied the progression for energy concept and discovered that although the idea of energy forms serves as a foundation for developing a deeper understanding of energy, the other ideas may not necessarily be developed in a distinct sequence. They found that students' progression in developing a scientific conception of energy was non-linear and complex. Most students' progression in terms of key ideas, conceptual development levels or both – showed a particular overlap between the hypothesized levels of development.

Implications

On the basis of our findings, we argue that science teachers should employ adaptive instruction on plant biology and experiential and inquiry learning in the garden-based education course. Different core ideas and their subordinate concepts vary in their difficulty, so the teachers should allocate time on them accordingly. The extra time should be given to make a connection between steps or the components for relational concept, for instance, and for the application of the understanding to solve real-world problems. We also recommend that teachers situate learning experience in their community so the "plant blindness" syndrome coined by Wandersee and Schussler (2001) is prevented. We encourage teachers to bring in the plants in context or go out to see the plants in a natural setting. Allow students to get close to see natural beauty and learn the science, their role in an ecosystem, and their economic value as well as use more plant examples to teach other biological concepts. We also see from the findings that students faced difficulty when learning an abstract concept. We recommend that teachers use multimedia and ICT-enhanced inquiry to represent the concept at the micro, macro, and symbolic level and urge them to make cross-level connection and presentation.

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Suggestions for Future Research

Several inquiries could be conducted to extend the findings of the current study. Rasch model could be conducted among subgroups of sample, for instance, by gender, learning environment, and socioeconomic status. In addition, it is advisable to conduct Rasch analysis to explore factors that potentially explain variation in LPs such as different educational environments leading to different learning trajectories. For example, Yao et al. (2017) examined whether two factors: School district (urban vs. suburban) and school type (normal and model) influenced Chinese students' progression rate. Furthermore, there are more advanced Rasch models that can be used to directly model the change in ability in pre- and post-testing situations such as multidimensional latent trait model (Embretson, 1991) and multidimensional random coefficients multinomial logit model (Adams et al., 1997).

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