

Interdisciplinary Problem-Based Sustainability Education: The Case of the CLIMASP-Tempus Minor

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Abstract Dealing with problems of environmental, economic and social concern emphasis is placed on developing learners' interdisciplinary and action competence to participate actively in building more sustainable futures. Higher education is called to play a critical role in this process. This paper deals with a European Commission funded programme CLIMASP that aims to develop interdisciplinary minors in climate change and sustainability policy in 10 Middle-Eastern universities. In this chapter, we present the results of the pre-test and post-test surveys that were carried out during the piloting phase in the spring semester of 2014–2015 academic year. Our aim was both to test reliability and validity of learning models as well as to examine possible changes during the implementation process. The statistical analyses show that the instruments are reliable, although improvement and enrichment is possible as well as increased changes experienced by students at the end of the piloting courses.

1 Introduction

The contemporary world, locally and globally, faces major problems such as poverty, genocides, climate change, violation of basic human rights and the deterioration of biodiversity, which cannot be left unsolved. It is widely recognized that these problems are beyond the scope of a particular academic discipline, and that their solution requires multiple ways of knowing. Interdisciplinary studies are broadly defined as the process of tackling challenging issues which addresses a problem that is so broad or complex that it cannot be tackled through a single discipline or field of study. Arguments favouring interdisciplinary teaching emphasize the need to bring multiple disciplinary perspectives to meaningfully tackling real-world issues such as climate change. Higher education plays a unique

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and critical role that is often overlooked in making a healthy, just and sustainable society employing interdisciplinary perspectives. Our focus here is the Middle East and North African (MENA) region, and more specifically Egypt, Jordan and Lebanon, countries that are heavily being threatened by climate change. Higher Education Institutions (HEIs) in the MENA region, in general, while recognizing that their region's contribution to the damage of the global climate is much less when compared to developed regions, they do recognize the urgency for tackling the challenge of climate change (Makrakis and Kostoulas-Makrakis 2014). Although interdisciplinary teaching and learning is highly prioritized in most of the MENA region (HEIs), in practice, there is lack of interdisciplinary perspective and motivation among teaching staff in undergraduate studies, with the exception of some interdisciplinary programmes within Master's and Ph.D. (Khadri 2014). The academic system is still very much structured on disciplines and the integration of interdisciplinary perspectives and programmes have become unusual to the undergraduate fields of study. This necessitates a shift to new organizational and administrative forms that differ from traditional academic departments and faculties alongside with new curricula and teaching methodologies such as problem-based learning (PBL). It has been suggested that interdisciplinary PBL has the potential to enhance students' collaborative learning skills and students' active learning participation (Imafuku et al. 2014; Hmelo-Silver 2012; Jonassen 2011; Walker et al. 2011).

As a response to these challenges, the UNESCO Chair ICT in Education for Sustainable Development (ESD) at the University of Crete has initiated and developed the CLIMASP project proposal that has been funded through the European Commission Tempus programme. CLIMASP adopts a multi/interdisciplinary and systemic approach that, at a wider level, aims to transform current unsustainable practices leading to climate change and promote interdisciplinary collaboration alongside with developing sustainable leadership in the partner countries' universities (Makrakis and Kostoulas-Makrakis 2015). Specific objectives, within the aforementioned wider ones, include the

- Development of capacity-building programmes to train university teaching staff and key administrators for interdisciplinary collaboration and building partnerships with local/national/regional partners;
- Involvement of university staff and other key stakeholders, (e.g. students, professionals and employers) in the development of an undergraduate interdisciplinary programme (minors) on climate change and sustainability policy in each partner country's university;
- Integration and implementation of the interdisciplinary minors as an integral part to existing undergraduate academic degrees in disciplines like education sciences, applied sciences, technical sciences, economics/business sciences and social sciences; and
- Monitoring, evaluation and review of the interdisciplinary programmes on climate change and sustainability policy in each partner country institution.

Interfaculty and interdisciplinary collaboration are essential for modernizing higher education and it is a necessary condition for any transformation to meeting the challenges of climate change and sustainable development in the MENA region. Climate change and other sustainability problems require interdisciplinary approaches that can bridge the compartmentalization of knowledge and the isolation of academic fields in order to facilitate policy choices towards a path of ecologically sound and socially equitable solutions. There is, thus, a critical need for Middle Eastern universities, in light of the climate change challenges their region is facing, to cultivate interdisciplinary expertise among their teaching staff and students.

2 The CLIMASP Minor

The key outcome of the CLIMASP project is the development of interdisciplinary minors in 10 partner universities in the MENA region (Egypt, Jordan and Lebanon). Each partner university has mapped out 25–30 undergraduate courses from at least three academic faculties based on certain criteria. Among the criteria are those of relevancy, faculty and staff interest and commitment. The interdisciplinary CLIMASP courses chosen have gone through a process of revising that aimed to embed sustainability into content and teaching methods. The CLIMASP courses are an integral part of the existing collaboration of undergraduate disciplines such as education sciences, technical sciences, economics/business sciences and social sciences. The minor consists of core courses, elective courses and the required capstone course in three concentration areas: (1) Climate Change, Environment and Society; (2) Climate Change, Economics and Public Policy; and (3) Climate Change, Science and Technology. Each of the core and elective courses is equivalent to six ECTS and the capstone course of 10 ECTS. The capstone course is based on an internship that provides a strong mechanism for integrating academic coursework with practical experience. The amount of minimum courses to be taken across the three concentration areas by undergraduate students to qualify for the CLIMASP minor is around 45–60 ECTS. This provides the students a formal credential through transcript documentation adapting the Europass supplement diploma to certify that they have developed leadership in the field of CLIMASP.

The CLIMASP minor is framed on an interdisciplinary modular structure that enables each partner institution to tailor CLIMASP according to its specific needs. For a smooth transition from disciplinary to interdisciplinary curricula, a piloting stage started in the spring academic semester 2014–2015 on a small number of CLIMASP courses. Piloting creates the opportunity to demonstrate what interdisciplinary learning and teaching looks like throughout the semester and allows faculty, students and evaluators to observe processes, methods and practices. Based on the pilot assessment, proper interventions to enhance content and methods will be applied to all the 240–300 CLIMASP course modules across the 10 partner universities.

3 Sustainability and Interdisciplinary Problem-Based Learning

The intersections between sustainability, interdisciplinarity and PBL exist at several levels and the CLIMASP project attempts to explore these links from various perspectives. The first challenge in that process was the need to better understand the intersections and the problems faced by university teaching staff and students. The second challenge was the importance of developing frameworks and the kind of tools needed to take interdisciplinary problem-based sustainability education forward in HEIs. Many scholars, (e.g. Hegarty 2008; Cotton et al. 2007; Huckle 2005; Sterling 2003; Bonnett 2002; Fien 2001) argue that the term sustainable development is contextually-bound and that sustainability or sustainable development is linked to our personal ethical and epistemological assumptions. As sustainability is an ethical, value-laden and moral goal/concept, the way it is defined, interpreted and understood will be eventually driven by our personal experiences and worldviews. Changing our value-system that is mainly the cause of the current sustainability crisis demands a new paradigm of thinking driven by transformative ways of knowing, thinking and learning (Makrakis and Kostoulas-Makrakis 2013a, b, 2014). A significant transformation is also required for universities in terms of what is taught, how it is taught and how disciplines are perceived and structured. Interdisciplinarity is the backbone of sustainability and PBL. In an interdisciplinary subject, students are encouraged to get involved in exploring and integrating multiple perspectives, drawing knowledge and tools from different disciplines. The core characteristic of interdisciplinary approaches is their goal to analyse, synthesize and integrate concepts, methods and principles from different disciplines (Lawrence 2010). This is different from what might be called a multidisciplinary subject which juxtaposes multiple perspectives on the same topic without integration and stays within their boundaries (Stock and Burton 2011) while transdisciplinarity creates a unity of intellectual frameworks beyond the disciplinary perspectives (Domik 2008; Choi and Pak 2006). Based on a thorough literature review, (e.g. Servant and Dewar 2015; Brush and Saye 2014; D'Ottavio and Bassan 2014; Leary et al. 2013) we found that interdisciplinary students need to

- Learn to interrogate multiple ways of knowing and methods and to talk critically but reasonably across these perspectives.
- Develop a reflective and explicit knowledge of how different disciplines work, the issues and problems they can address, and the strengths and limitations of each discipline.
- Balancing, weighing and accommodating a variety of disciplinary perspectives in order to reach a reasonable and creative decision or outcome.
- Understand that there are several important disciplinary perspectives that are relevant to every sustainability decision.
- Think critically, communicate effectively, and work collaboratively when addressing and solving the complex sustainability problems facing humanity.

These skills and understandings are vitally important to support problem solving and sustainability decision-making. In the second half of the twentieth century, much of the discussion on skills needed was centred on the 3Rs—reading, writing, and arithmetic. In the past decade, there was a shift to what has been termed as the 4Cs for workforce readiness in the twenty-first century—critical thinking and problem solving, communication, collaboration and team building and creativity and innovation (AMA 2010; Partnership for twenty-first century skills 2012; AT21CS 2012). In a world of rapid change and expansion of human knowledge, along with sustainability crisis that threatens the very existence of humankind, education must extend beyond the focus on the 4Cs to what we term 10Cs (Makrakis and Kostoulas-Makrakis 2014), namely

1. Critical thinking and problem solving
2. Communication
3. Collaboration
4. Creativity and innovation
5. Connectivity
6. Critical consciousness
7. Critical reflection
8. Cross/inter-cultural competence
9. Co-responsibility
10. Constructing knowledge

Although there is some overlap among the 10Cs, each one has its own role in teaching and learning for problem solving. For example, critical thinking and problem solving refers to the ability to make decisions, solve problems and take appropriate action, using learning processes such as conceptualizing, applying, analysing, synthesizing and/or evaluating information gathered by multiple means. Communication refers to the ability to synthesize and transmit ideas in written, oral and virtual formats. Collaboration refers to the ability to work effectively with others, including those from diverse groups and with opposing points of view. Creativity and innovation refers to the ability to apply new ideas in developing innovative applications and solutions. Connectivity addresses the complexity of human-to-human interaction as well as to society and nature. This is driven by the theory of connectivism—a response to a need to derive and express meaning, and gain and share knowledge, in an increasingly networked global society (Siemens 2004, 2006). These connections occur on neural, conceptual and social levels (Siemens 2008). Critical reflection refers to a complex process that strongly engages learners to critically reflect upon their reality, personal and social, and to transform it through action and reflection (Stanlick 2014). Cross/inter-cultural competence requires that learners examine their own cultural backgrounds and identities to increase awareness of personal assumptions, values and biases in order to work effectively in cross-cultural situations. Co-responsibility refers to a culture of sharing that necessitates shifting to less ego-centric principles and practices. Critical consciousness or conscientization in Freire's (2000) terms denote the process of developing a critical awareness of one's social reality through reflection

and action. Constructing knowledge represents an attempt to shift from consuming information to constructing knowledge that merges with action.

The sustainability crisis is not just our biggest environmental, economic and social challenge; it is also a cultural challenge, a personal and moral one due to its anthropogenic cause (Kostoulas-Makrakis and Makrakis 2012). There is, thus the need for a shift of consciousness that alters: our way of being in the world (learning to be), our way for discovering others by discovering ourselves (learning to live together), our way of learning how to learn as well as appreciating all sorts of knowing (learning to know) and our way of putting knowledge into action (learning to do). It is above all learning to “transform oneself and society”, what Mezirow (2003, p. 58) refers to “problematic frames of references—sets of fixed assumptions and expectations (habits of mind, meaning perspectives, mindsets)—to make them more inclusive, open, reflective and emotionally able to change”. The first four of these pillars were addressed in the 1996 report to UNESCO; *Learning: The Treasure Within*, The International Commission on Education for the twenty-first century, “provide maps of a complex world in constant turmoil” as well as “the compass that will enable people to find their way in it” (Delors et al. 1996, p. 85). At a later stage, the fifth pillar of learning to transform oneself and society was added by UNESCO. We feel the need to add the sixth pillar of ‘learning to give’ in order to respond to the quest for merging volunteerism, social activism and learning (Fig. 1; Table 1).

All these processes can be significantly promoted through instructional and learning methods that focus on reflection and action to generate solutions such as PBL. PBL is not solely regarded as an instructional technique, but as an educational philosophy or approach for designing curricula that “empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem” (Savery 2006, p. 12). It is also one of the learning strategies that are often used to reorient university curricula and teaching methods to address sustainability. Most ESD research documents that PBL pedagogies can provide are a framework for developing sustainability education (Guerra 2014). Focusing on sustainability problems, PBL provides learners with opportunities to move beyond surface learning by placing students in the active role of problem-solvers confronted with sustainability issues.

The proposed PBL framework consists of a number of key interacting processes depicted in Fig. 2 and Table 2, which facilitate the theoretical and methodological clarification and understanding of the PBL as an instructional and curricular approach. Each interacting process integrates various skills drawn from the 10Cs. Furthermore, it takes into consideration the contribution of the problem-solver and the potential impact that he/she brings to the outcome of problem solving process. It also gives primacy on a practical and critical reflective knowledge interest. The importance of the practical and critical reflective knowing is embedded in constructing knowledge and meaning merged with personal and social action.

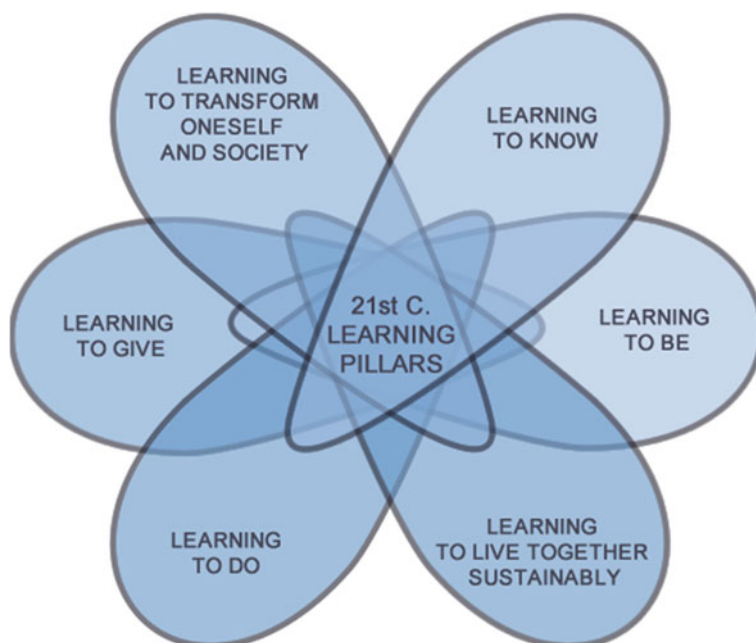


Fig. 1 Twenty-first century learning pillars

Table 1 Definition of the twenty-first century learning pillars

Learning to know	This type of learning concerns all the processes and practices that lead people to experience, construct and transform knowledge for making sustainability a mode of life and being
Learning to be	This type of learning concerns all the processes and practices that lead to human self-actualisation, self-regulation and cultivating a sense of being versus having
Learning to live together sustainably	This type of learning concerns all the processes and practices that lead to a peaceful and non-discriminatory society and human co-existence with the natural world
Learning to do	This type of learning concerns all processes and practices that lead to merging knowledge with action for building a sustainable future
Learning to transform oneself and society	This type of learning concerns all the processes and practices to transform their unsustainable values and behaviours and collectively engage to change society towards sustainability
Learning to give and share	This type of learning promotes solidarity and caring attitudes to meet human needs as learners gain autonomy and purpose for their learning and civic engagement

Fig. 2 The interdisciplinary PBL processes



The processes represented into the two PBL models are re-conceptualized into a methodological framework depicted in Fig. 3. This framework functions as an organizer for designing, developing, applying and assessing a PBL approach contextualized in the area of education for sustainability. We expect that our approach provides a means towards building learning-based change that will ultimately contribute to building a more sustainable society.

4 Developing and Validating an Instrument for Measuring Interdisciplinary Problem-Based Sustainability Learning

Based on our previous approaches regarding the intersections of sustainability and interdisciplinary PBL, we have used certain scales in our pilot phase for the CLIMASP minor in climate change and sustainability policy during the spring

Table 2 The PBL key processes and their description

PBL processes	Description
Raising a problem	It is a process that challenges learners to raise an authentic and meaningful problem
Brainstorming about the problem	It is a creative thinking process that helps learners to reflect and build on their prior knowledge
Developing claims/propositions	In this process, problem-solvers elaborate the initial state of the problem and identify debatable claims or propositions
Linking claims to evidence	In this process, claims have to be linked to supportive evidence (facts, beliefs, statements and assumptions)
Arguing on evidence-based problem solutions	In this process, it is essential to develop sound and persuasive argumentation grounded on evidence and supportive facts or conjectures
Acting on proposing solutions	It is the process that turns problem-solvers' acquired and constructed knowledge, meaning, understandings and concerns into responsible action
Scaffolding	Scaffolding is generally regarded as support for learners while they are engaged in PBL activities just beyond their own capabilities
Reflecting and assessing PBL processes	Reflecting and assessing are ongoing processes that give students the opportunity to reflect on their own learning, highlight what they have learned, explain important decisions they have made, and articulate plans for incorporating feedback and moving forward

semester of the 2014–2015 academic year. The first scale concerns the six pillars of learning. As far as the four learning pillars (learning to know, learning to be, learning to live together and learning to do) are concerned, the scale was based on the respective competences identified in the UNECE competence scale (cited in Dlouhá et al. 2010) that is connected with Bloom's taxonomy of learning domains. The other two sub-scales of learning to transform oneself and society and learning to give and share are based on our own measurement terms. The *Cronbach alpha* reliability analysis with a sample of 445 students from two CLIMASP partner universities (Jerash University (No = 326), Jordan and Suez Canal University (No = 119), Egypt) indicated that the scales measuring the six pillars of learning (Table 3) exhibited very high reliability indices ranged from $\alpha = 0.84$ to 0.94.

The second scale concerned with the 10Cs, also based on our own conceptualisation, exhibited a very high *Cronbach alpha* reliability value equal to 0.96 (Table 4). Similarly, the reliability analysis for the scale measuring student-centred and instructor-centred teaching methods showed high reliability results that in total reached to 0.95 for the scale measuring student-centred teaching and learning methods and 0.90 for the instructor-centred teaching and learning methods (Table 5). This scale was based on 14 items of which three accounted for instructor-centred teaching and learning and the rest to student-centred teaching and learning approaches.

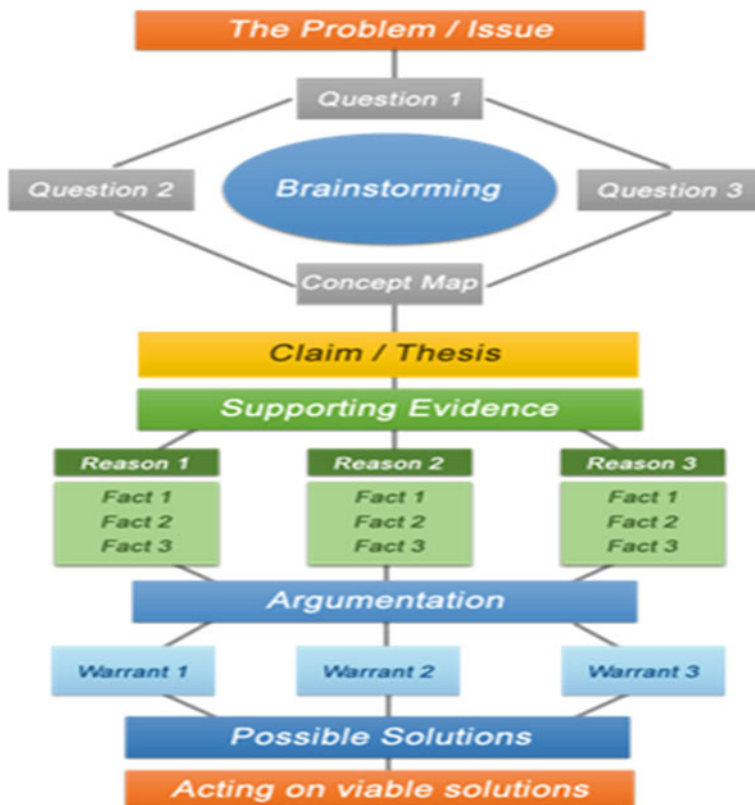


Fig. 3 The PBL organizing framework

Finally, the interdisciplinary PBL scale was modified from the one used by Lattuca et al. (2012). This scale has three key components (1) interdisciplinary skills (eight items); (2) reflective behaviour (two items) and (3) recognizing disciplinary perspectives (three items). As pointed by Lattuca et al. (2012), the interdisciplinary skills scale assesses students' perceptions of their abilities to think about and use different disciplinary perspectives in solving interdisciplinary problems or to make connections across academic fields. The reflective behaviour scale includes items that operationalize the "reflexivity" dimension of interdisciplinarity. This scale includes items that reflect students' perceived ability to recognize the need to reconsider the direction of their thinking and problem solving approaches. The final part of the scale, recognizing disciplinary perspectives, measures students' perceived understandings of disciplinary knowledge, methods, expectations and boundaries and how disciplinary knowledge might be applied in different situations. Each of these three factors, according to Lattuca, Knight and Bergom, exhibits high internal consistency, with *Cronbach's alpha* values ranging from 68 to 79. As depicted in Table 6, the reliability test exhibited even higher *Cronbach's alpha*

Table 3 The six learning pillars scale

Learning pillars	Items corresponding to each learning pillar	Alpha if item deleted	Item means
Learning to know/learn (alpha = 0.94) Total items mean = 3.3	Posing analytical questions/critical thinking	0.93	3.4
	Understanding complexity/systemic thinking	0.92	3.0
	Overcoming obstacles/problem solving	0.93	3.4
	Managing change/problem-setting	0.93	3.4
	Creative thinking/future-oriented thinking	0.93	3.3
	Understanding interrelationships across disciplines/holistic approach	0.92	3.3
Learning to be (alpha = 0.92) Total items mean = 3.5	Feeling self-confidence	0.90	3.4
	Self-expression and communication	0.90	3.5
	Coping under stress	0.89	3.5
	Identifying and clarify values	0.89	3.5
Learning to live and work together (alpha = 0.94) Total items mean = 3.2	Acting with responsibility (locally and globally)	0.94	3.6
	Acting with respect for others	0.94	3.5
	Identifying stakeholders and their interests	0.94	2.5
	Collaboration/team working	0.93	3.3
	Participating in democratic decision-making	0.93	3.2
	Negotiation and consensus building	0.93	3.0
	Distributing responsibilities (subsidiarity)	0.93	3.2
Learning to do (alpha = 0.94) Total items mean = 3.4	Applying learning in a variety of life-wide contexts	0.93	3.4
	Decision-making, including in situations of uncertainty	0.93	3.4
	Dealing with crises and risks	0.92	3.4
	Acting responsibly	0.93	3.5
	Acting with self-respect	0.93	3.4
	Acting with determination	0.93	3.4
Learning to transform oneself and society (alpha = 0.90) Total items mean = 3.5	Acting personally and collectively for the common good	0.84	3.4
	Acting responsibly for social and economic injustices	0.92	3.4
	Acting for environmental integrity	0.83	3.6

(continued)

Table 3 (continued)

Learning pillars	Items corresponding to each learning pillar	Alpha if item deleted	Item means
Learning to give and share (alpha = 0.84) Total items mean = 3.25	Giving and sharing from own resources	–	3.4
	Connecting learning with volunteering	–	3.1

Table 4 The 10Cs and their measurement items

Factor 10Cs (alpha = 0.96) Items mean = 3.4	Items corresponding to each critical skill	Alpha if item deleted	Item means
Critical thinking and problem solving	Making reasoned judgments that are logical, well thought out and reflective	0.96	3.6
Communication	Sharing thoughts, questions, ideas and solutions effectively and efficiently	0.96	3.5
Collaboration	Working together to efficiently and actively achieve a defined goal	0.96	3.5
Creativity and innovation	Turning new and imaginative ideas into reality	0.96	3.5
Connectivity	Linking to and communicate with others by using multiple means of communication	0.96	3.5
Critical consciousness	Perceiving social, environmental, and economic oppression and take action	0.96	3.4
Critical reflection	Questioning assumptions, presuppositions, and meaning perspectives	0.97	3.6
Cross/inter-cultural competence	Communicating effectively and appropriately with people and cultures	0.96	3.4
Co-responsibility	Being responsible, answerable or accountable for something within one's power, control or management	0.96	3.5
Constructing knowledge	Constructing new knowledge and meaning upon previous experiences and ideas	0.96	3.4

values ranging from 0.88 (Reflective behaviour) to 0.90 (Recognizing disciplinary perspectives) and 0.95 (Interdisciplinary skills). Although, the scores are very high, it is our perception that there is need to enrich the scales with the fewer items with more items. The *Cronbach's alpha* reliability analysis was based on the post-test items of the measured scales as the students participated in the survey were more familiar with the concepts that the items of the scales were composed.

Table 5 Student-centred and instructor-centred learning and teaching methods

Teaching and learning methods	Items corresponding to student-centred and instructor-centred learning and teaching methods	Alpha if item deleted	Item means
Student-centred teaching (alpha = 0.96) Total items mean = 2.8	In classes, the discussion was led by both the instructor and students	0.96	3.7
	Connecting the course content with volunteering in the community	0.96	3.1
	Connecting the course content with practice outside the university	0.96	2.6
	Connecting course content with online learning	0.95	2.6
	Asked to reflect on what I have learned and think	0.96	3.3
	Asked to do a project with real life issues/problems collaboratively	0.96	3.2
	Asked to make a presentation in class	0.96	2.6
	Asked to solve a real life issue/problems and provide solutions	0.97	2.8
	Asked to solve a real life issue/problem based on problem-based learning	0.96	2.6
	Asked to review/criticize the work of other students	0.97	2.3
	Asked to keep a portfolio for all class activities	0.96	1.8
Teacher-centred teaching (alpha = 0.93) Total items mean = 2.3	In classes, the instructor led the course	0.90	2.8
	In classes the instructor led the discussion	0.92	2.7
	Asked to write down a final class exam	0.90	1.6

5 Measuring Changes in Interdisciplinary Problem-Based Sustainability Learning

One of the key aims of the CLIMASP pilot phase carried out in the spring semester of 2014–15 was to find out what changes have occurred as a result of the revised courses implemented. The change effects were measured through the use of paired-samples t-test by calculating the differences between the two measures. A pre-test/post-test evaluation is an assessment method that is administered at the beginning and at the end of a course. As pointed earlier, here we use the data collected from two partner institutions in Egypt and Jordan with a total sample of 445 students. When comparing pre-test and post-test class point scores for the whole group, the results show that significant changes occurred as a result of the course content and methods and teaching methods (Table 7).

Examining the results in the interdisciplinary problem-based scale, we find that the average total pre-test mean ranged from 2.87 to 2.98 on a four-point scale

Table 6 Dimensions of the interdisciplinary scale and their measuring items

Factor	Interdisciplinary items	Alpha if item deleted	Item means
Interdisciplinary skills (alpha = 0.95) Total items mean = 3.5	I value reading about topics outside of my own field/subject	0.94	3.4
	I enjoy thinking about how different fields approach the same problem in different ways	0.94	3.5
	Not all problems have purely technical solutions	0.94	3.4
	In solving problems I often seek information from experts in other academic fields	0.95	3.4
	Given knowledge and ideas from different fields, I can figure out what is appropriate for solving a problem	0.94	3.5
	I see connections between ideas in my study/subject field and ideas in other study/subject fields	0.94	3.5
	I can take ideas from outside my field and synthesize them in ways that help me better understand what I study	0.95	3.5
	I can use what I have learned in one field in another setting	0.94	3.4
Reflective behaviour (alpha = 0.88) Total items mean = 3.4	I often step back and reflect on what I am thinking to determine whether I might be missing something	–	3.5
	I frequently stop to think about where I might be going wrong or right with a problem solution	–	3.4
Recognizing disciplinary perspectives (alpha = 0.90) Total items mean = 3.4	If asked, I could identify the kind of knowledge and ideas that are distinctive to different fields of study	0.83	3.4
	I recognize the kind of evidence that different fields of study rely on	0.87	3.3
	I'm good at figuring out what experts in different fields have missed in explaining a problem/solution	0.86	3.4

(Strongly Agree, Agree, Disagree and Strongly Disagree) and the average post-test mean from 3.44 to 3.45, yielding an average statistically significant difference of +0.52. In terms of the three sub-scales, the statistically significant difference measured through the paired-sample t-test were for (1) interdisciplinary skills, $t(444) = -9.29$, at $p < 0.001$; (2) reflective behaviour, $t(444) = -6.59$, at $p < 0.001$; and (3) recognizing disciplinary perspectives, $t(444) = -7.57$, at $p < 0.001$.

Table 7 Pre-test and post-test comparisons of the interdisciplinary problem-based sustainability education scales and sub-scales

Scale	Type	Mean	t-test	d.f.	Sig.
Interdisciplinary skills	Pre-test	2.87	-9.29	444	0.000
	Post-test	3.45			
Reflective behaviour	Pre-test	2.98	-6.59	444	0.000
	Post-test	3.44			
Recognizing disciplinary perspectives	Pre-test	2.87	-7.57	444	0.000
	Post-test	3.36			
10Cs	Pre-test	2.12	-21.64	440	0.000
	Post-test	3.45			
Learning to know	Pre-test	2.12	-18.99	439	0.000
	Post-test	3.48			
Learning to be	Pre-test	2.96	-8.43	442	0.000
	Post-test	3.48			
Learning to live together	Pre-test	2.86	-5.04	441	0.000
	Post-test	3.17			
Learning to do	Pre-test	2.75	-11.03	443	0.000
	Post-test	3.42			
Learning to transform	Pre-test	2.93	-9.45	444	0.000
	Post-test	3.53			
Learning to give and share	Pre-test	2.74	-7.05	444	0.000
	Post-test	3.25			
Student-centred teaching methods	Pre-test	1.67	-17.88	445	0.000
	Post-test	2.79			
Instructor-centred teaching methods	Pre-test	2.59	3.86	444	0.000
	Post-test	2.35			

Regarding the scale measuring the 10Cs, the statistical analysis shows that the pre-test average total items mean was 2.12 on a four-point scale and the average post-test total items mean 3.45, yielding a statistically significant difference of +1.36 with, $t(440) = -21.64$, at $p < 0.001$. This is the highest change effect, which shows clearly that the CLIMASP pilot courses did have a great effect across all the 10 critical skills namely, critical thinking and problem solving; communication; collaboration; creativity and innovation; connectivity; critical consciousness; critical reflection; cross/inter-cultural competence; co-responsibility and constructing knowledge. Looking into the results of the six learning pillars, it has been revealed that the average total pre-test mean ranged from 2.12 to 2.96 (Total Mean = 2.73) on the four-point scale and the average post-test mean from 3.17 to 3.48 (Total Mean 3.39), yielding an average statistically significant difference of +0.66. The statistically significant differences across the six sub-scales were learning to know, $t(439) = -18.99$, at $p < 0.001$; learning to be, $t(442) = -8.43$, at $p < 0.001$; learning to live together, $t(441) = -5.04$, at $p < 0.001$; learning to do, $t(443) = -11.03$, at

$p < 0.001$; learning to transform oneself and society, $t(444) = -9.45$, at $p < 0.001$; and learning to give and share, $t(444) = -7.05$, at $p < 0.001$.

Finally, with respect to the scale measuring student-centred and instructor-centred learning and teaching methods, the pre-test/post-test analysis revealed a statistically significant difference in their means. More specifically, on the one hand, the pre-test measurement of student-centred teaching and learning methods revealed a total average mean equal to 1.67 and the post-test value reached 2.79 on a four-point scale (Not at all, few times, often and very often), yielding a difference of +1.12 with $t(444) = -17.88$, at $p < 0.001$. The second highest change effect among all scales and sub-scales. On the other hand, the results of the sub-scale measuring instructor-centred teaching and learning methods revealed a statistically significant difference but in different directions. The average pre-test score was 2.59 and the post-test score 2.35, yielding a slight but statistically significant decrease of -0.24 . These two results show that besides adopting and implementing student-centred teaching and learning methods in the piloting CLIMASP courses, the instructor-centred teaching/learning methods are clearly giving their way to more suitable sustainability education methods.

6 Concluding Remarks

As pointed in the introduction, there was need for an instructional design framework for the CLIMASP minor that helps teaching staff to better understand the theory and methodology of interdisciplinary PBL sustainability education and enable them to adapt it as needed for their own teaching and learning environments. In such kind of learning environment, learners tackle sustainability problems, develop debatable claims and link them with supportive evidence, interact with a wide variety of learning resources, and develop argument-based solutions to those problems. Further, they develop action competence as a means for engaging learners in problem solving and provide with a framework that enables learners to take individual or collective action to the proposed solutions.

While piloting a number of CLIMASP courses in the partner universities, we employed a pre-test/post-test instrument that reflects our teaching and learning methodologies conducive to sustainability education. Our aim was to test reliability and validity of learning models and to examine possible changes during the implementation process. The statistical analyses show that the instruments are reliable, although improvement and enrichment are possible, despite the very satisfactory reliability values found. In terms of changes, starting from the apparent shift from instructionist to constructivist and critical pedagogy methods alongside the significant changes occurred in students' interdisciplinary PBL sustainability skills and competences, it seems that the CLIMASP course revision process achieved its objectives. As part of this approach students are given the opportunity to compare their ideas with their peers and their teachers, whilst contributing to co-constructing their course content in a meaningful manner. In this context,

students are asked to reflect, analyse and critique what they are learning and how they are learning it, to solve a real-life issue/problem, review/criticize the work of other students and keep a portfolio for all class activities. Through these approaches students take ownership of their own learning as they can influence the whole learning process and curriculum. In other words, students and learning are placed in the centre of the learning process while the instructor provides them with opportunities to learn independently, think critically and envisioning sustainable futures. At the same time, instructors function as coaches. Learner-centred university instructors teach students how to learn, to be, to do, to live together with others, to transform oneself and society as well as to learn to give and share. Through these they learn how to pose analytical questions, understanding the complexity of sustainability issues, applying multiple ways of thinking and knowing and acting responsibly for social and economic injustices. Through these processes, interdisciplinary thinking and learning can be integrated into content, methods and human habits. All these processes are enabled through critical skills like the 10Cs that include, making reasoned judgments that are logical, well thought out and reflective, sharing thoughts, questions, ideas and solutions effectively and efficiently, questioning assumptions, presuppositions, and meaning perspectives and finally turning new and imaginative ideas into reality.

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