Cite as: L. G. Pee (forthcoming) Enhancing the learning effectiveness of ill-structured problem solving with online co-creation, Studies in Higher Education

Enhancing the Learning Effectiveness of Ill-structured Problem Solving with Online Co-creation

L. G. Pee
Nanyang Technological University
31 Nanyang Link, #05-06, Singapore 637718
Email: peelg@ntu.edu.sg; Tel: (65) 6790-4579

Abstract

Ill-structured problem solving is widely believed to promote learning in higher education but its multiplicity (i.e., multiple solutions and evaluation criteria) is often seen as a challenge to manage. This study shows that the multiplicity can be managed as well as leveraged to enhance learning effectiveness through online co-creation. Three co-creation activities are identified and their effects on different aspects of learning effectiveness are assessed in a study involving 225 tertiary-level students. Results indicate that solution co-creation and solution sharing enhance cognitive learning (e.g., perceived knowledge about a subject topic), while decision co-creation enhances epistemic learning (e.g., perceived understanding of criteria of knowing). The findings demonstrate the value of online co-creation and the pave the way for more research on online co-creation in other collaborative pedagogical practices.

Keyword: Co-creation, learning effectiveness, Internet technology

Enhancing the Learning Effectiveness of Ill-structured Problem Solving with Online Co-creation

L. G. Pee
Nanyang Technological University
31 Nanyang Link, #05-06, Singapore 637718
Email: peelg@ntu.edu.sg; Tel: (65) 6790-4579

1. Introduction

The multiplicity of ill-structured problem solving (ISPS) is a double-edged sword in learning, potentially enhancing learning effectiveness (Yew and Goh 2016) but inherently challenging to manage for the instructor as well as learners (Collins et al. 2016; Savery 2015). Ill-structured problems refer to those with multiple solutions, greater uncertainty about which concepts, rules, and principles are necessary for the solution and which solution is the best (Jonassen 1997; Reed 2016). ISPS promotes learning by virtue of being a contextual, constructive, self-directed, and collaborative process that positions learners as active knowledge seekers addressing authentic problems (Marra et al. 2014). ISPS is expected to enhance cognitive learning (e.g., knowledge about a subject topic) and epistemic learning (e.g., understanding of the criteria of knowing; Jonassen 1997). In the long term, it helps to develop lifelong learners for an increasingly dynamic and complex work environment.

ISPS is challenging to implement and manage, as the instructor needs to determine a representative and appropriate set of evaluation criteria among many and be able to evaluate many different solutions. Concomitantly, learners also need to embrace the multiplicity and consider as many different solutions as possible to maximize their learning, while juggling limited cognitive resources and time constraints (Savery 2015). Prior research has focused on prescribing the process of ISPS (e.g., learning strategies and curriculum designs) or assessing its learning effectiveness (Hallinger and Bridges 2017; Yew and Goh 2016). In comparison, our understanding of how to manage the multiplicity has remained limited.

This study proposes that online co-creation could *leverage* the multiplicity of ISPS to improve learning effectiveness. Online co-creation is the joint, collaborative, peer-like process of producing new value, which can be material, symbolic, or both (Marco and Daniele 2014). Online co-creation is rapidly emerging as a new approach for creating innovative products and services in businesses. The approach emphasizes consumers' active interaction, empowers consumers to make decisions regarding the design of products and services, and ensures that the created value is shared by all participants (Füller et al. 2009; Prahalad and Ramaswamy 2004). Co-creation is also gaining traction in education research and practice, albeit mostly at the university and program levels (Fagerstrom and Ghinea

2013; Thatcher et al. 2016). In this study, we propose that online co-creation can leverage the multiplicity of ISPS, that is, exploit the opportunity offered by the multiplicity of ISPS to improve learning.

Internet technologies such as online discussions and voting are essential in online co-creation. Their asynchronicity minimizes physical and temporal limitations and makes it easier for users to participate in co-creation. When applied to learning, research has shown that Internet technologies place less demand on turn taking and allows multiple learners to communicate simultaneously or even participate in multiple discussions at the same time. They also allow learners more time to structure and organize their thoughts before asking a question or making a statement (Cheng et al. 2011). Therefore, Internet technologies are likely to play important roles in online co-creation for ISPS.

The effectiveness of online co-creation at the course level has not been examined. We propose that online co-creation is likely to be especially useful for ISPS because the multiplicity in solution and evaluation criteria calls for an approach that allows learners to work with one another to co-create solutions, co-create evaluation criteria and judgment, and share the multiple solutions. More importantly, online co-creation affords learners the opportunity to interact and learn more from understanding and evaluating multiple solutions proposed by others compared to when the solutions are not shared. This leads to better understanding of the course materials and ultimately a better learning experience.This study seeks to examine how online co-creation can be leveraged to improve learning effectiveness and addresses the research question: How does online co-creation affect the learning effectiveness of ill-structured problem solving? Results of a survey of 225 tertiary students indicate that solution co-creation and solution sharing enhance perceived cognitive learning, while decision co-creation (i.e., selection of evaluation criteria) enhances perceived epistemic learning.

This study's findings add value to research and practice in several ways. First, this study contributes to research on ISPS in learning by showing that the multiplicity of ISPS can be *leveraged* to improve learning effectiveness through online co-creation. Second, we provided empirical evidence that online co-creation significantly increases different aspects of learning effectiveness. From a practice perspective, this indicates the need to further develop and understand online co-creation in other collaborative pedagogical practices. In particular, for course instructors, this study demonstrated that online co-creation can be readily implemented with the Blackboard system, which is one of the top three learning management systems worldwide.

2. Conceptual background

To conceptualize online co-creation in ISPS, we first review ISPS in learning and its challenges. This is followed by a review of the co-creation literature to identify its key principles, which form the basis for conceptualizing online co-creation in ISPS. To clarify the unique contribution of online co-creation to ISPS, we also compare ISPS with and without online co-creation.

2.1. Ill-structured problems in learning

Ill-structured problems refer to those with multiple solutions, uncertainty about which concepts, rules, and principles are necessary for developing the solution and which solution is the best (Jonassen 1997; Reed 2016). Ill-structured problems constitute an important aspect of many learning approaches, including problem-based learning, action learning, and collaborative learning. Problems are clearly integral in problem-based learning, which begins with a problem that learners address before receiving curriculum input (Schmidt 1983). Learners rely on their prior knowledge to understand the problem (Yang et al. 2018) and identify knowledge gaps that form the basis of their self-directed learning. Action learning emphasizes taking action and reflecting upon the results (McGill and Beaty 2001), and often begins with a problem that is amenable to at least partial solution within a reasonable time frame. Problem solving is also a commonly-used learning activity in collaborative learning, in which two or more learners work together to complete a learning activity (Bruffee 1993). The collaboration enhances learning by allowing learners to exercise, verify, improve, and solidify their mental models through social interactions during problem solving.

Ill-structured problem solving (ISPS) is expected to enhance learning effectiveness, especially cognitive learning and epistemic cognitive learning (Jonassen 2010; Kitchner 1983). Cognitive learning refers to the understanding of key concepts related to a problem, solutions, and the corresponding justifications. Problem solving facilitates cognitive learning by offering opportunities for learners to engage in cognitive operations which involve domain and structural knowledge. Epistemic learning refers to understanding of the criteria of knowing, the certainty of knowing, and limits of knowing related to a problem. In other words, it focuses on a learner's ability to assess a solution based on evaluation criteria, learner's confidence in the knowledge used for the solution, and learner's understanding of the solution's limitation. Problem solving facilitates epistemic learning by requiring learners to consider different potential solutions and their truth values in order to select one for further development (Jonassen 1997).

Despite its potential contribution, ISPS is challenging to both the instructor and learners due to the complexity involving multiplicity in solution and evaluation criteria. For the instructor, the multiplicity can make it difficult to evaluate learners' solutions for benchmarking and assessing their learning (Collins et al. 2016). The instructor's evaluation could be laden with personal belief or subconscious biases (Nespor 1987). For learners, although the multiplicity in solution offers much opportunity to learn diverse knowledge, they often face practical constraints in cognitive resources and time that inhibits their exploration of different solutions (Savery 2015). This can limit the learning effectiveness of ISPS. In this study, we propose that online co-creation can leverage the multiplicity of ISPS to improve learning effectiveness. Co-creation is reviewed next.

2.2. Co-creation principles

Co-creation is the joint, collaborative, peer-like process of producing new value, which can be material, symbolic, or both (Marco and Daniele 2014). Co-creation is increasingly embraced in businesses, where it is seen as a social process based on interactions between firms and external stakeholders, oriented toward the development of new products or services (Ramaswamy and Ozcan 2018). The public sector is also beginning to explore the co-creation of public value, such as in policy making (Bryson et al. 2017). Co-creation especially useful because the action to public value often involves multiple stakeholders and takes place at multiple levels. This requires input from multiple perspectives and co-creation allows multiple logics to be considered and accommodated.

Given the fairly emergent state of the co-creation paradigm, its conceptual development is best characterized as underway rather than established. Seminal works in the management literature identify the key principles of co-creation to be (see summary in Table 1):

1) Value co-creation: Participants actively and jointly produce value online (e.g., products, services) through social interactions,
2) Decision co-creation: Participants are empowered to make important decisions affecting product or service value through online voting,
3) Value sharing: The co-created value benefits all participants.

Together, these principles capture the essence of the co-creation approach regarding the means and outcome of value creation. These principles will be the basis for conceptualizing online co-creation in ISPS.

Table 1. Key Principles of Co-Creation Conceptually Rooted in Management Research

Key Principle / Source	Value co-creation (i.e., value added to products/services)	Decision co-creation	Value sharing
Grönroos (2011)	Customer participants create value, and the firm facilitates the process of value creation	Customer participants are in charge, directly and actively influencing the flow and outcome of the co-creation process	Value is created reciprocally
Lee and Kim (2018)	Customers and firms collaborate in product ideation, design, testing, support, and marketing	*(not discussed)*	Customers expect to benefit in terms of better understanding and knowledge about the products/services, such as the underlying technology and usage

Table 1. Key Principles of Co-Creation Conceptually Rooted in Management Research			
Payne et al. (2008)	- Customer participants are at the same level of importance as the company as co-creators of value - Firms can "teach" customers certain co creation behaviors, by supporting customers' ongoing learning about offerings and processes - Relationships are developed through interactions and dialogues	*(not discussed)*	*(not discussed)*
Prahalad and Ramaswamy (2004)	- Joint problem definition and problem solving - Creating an experience environment in which consumers can have active dialogue and co-construct personalized experiences	Customer participants want to/is being empowered to co-construct a personalized experience around themselves	*(not discussed)*
Vargo et al. (2008)	Consumers co-create value through the integration of firm provided resources with other private and public resources (e.g., information, experience)	Value is uniquely and phenomenologically determined by the beneficiary	Mutually beneficial relationships in value co-creation

Co-creation is also gaining traction in education, albeit mostly at the university and program levels (Dollinger et al. 2018). Table 2 summarizes some co-creation initiatives and the co-creation principles realized. The review indicates two gaps: 1) Although empowering participants is a key principle of co-creation, students in co-creation initiatives still have very little power to influence decisions regarding the output and its quality; 2) Existing co-creation initiatives are mostly at the university or program levels. The applicability and usefulness of co-creation in classrooms/at the course level are still unclear. As discussed earlier, co-creation can potentially addresses the challenge of multiplicity in ISPS. This project reduces these gaps by embracing the empowerment principle and evaluating the co-creation approach in classes.

Table 2. Review of Co-Creation in Education			
Co-creation principle	Solution co-creation (i.e., solution to ill-structured problem)	Decision co-creation	Value sharing
Source			
Fagerstrom and Ghinea (2013)	University applicants, current students, and university representatives interacted on a social networking website to share program information and experience	*(Students did not make any decision)*	Applicants could clarify questions, while the university acquired knowledge about applicants and built relationships that increase the likelihood that applicants accept offers
Stevenso et al. (2015)	University students in Finland, Austria, and Germany worked together to co-create educational videos to support reflection and engagement on a particular topic	*(Videos were evaluated by a panel of judges to choose the best videos, using pre-determined criteria such as educational quality, technical quality, and creative quality)*	Videos were expected to be useful for future student learning and faculty teaching
Thatcher et al. (2016)	Academics/faculties, graduate research students, and businesses collaborated in micro and small business research projects	*(Academics provided researchers with direction, guidance and support)*	Students gained opportunities to apply theories and research skills; businesses gained access to consultancy services and research; academics developed professional network
Trencher et al. (2015)	Students were integrated into faculty-led research partnerships for the co-creation of knowledge and social experiments for advancing sustainability, through masters or doctoral research, social experiments and stakeholder interactions, faculty research assistance, and project planning and management	*(Not discussed. Mostly faculty led)*	Students gained experience in applying theories and knowledge, while faculties gained enriched perspectives from multiple stakeholders

2.3. Online co-creation in ill-structured problem solving

Based on the principles of co-creation (see section 2.2) and considering that the value of ISPS is embodied in solutions, we conceptualize online co-creation in ISPS to be:

1) Solution co-creation: Learners actively and jointly develop solutions through online

social interactions,

2) Decision co-creation: Learners are empowered to make key decisions regarding the evaluation criteria and the best solution through online voting,

3) Solution sharing: The co-created solutions are accessible online to all participants for their benefit.

Compared to the typical ISPS, ISPS with online co-creation leverages the multiplicity of ill-structured problems in various phases of ISPS. In problem definition, students are empowered to suggest and vote for relevant evaluation criteria online, adding to the criteria determined by the instructor. This is in line with the multiplicity of evaluation criteria in ISPS and helps to reduce subjectivity. In problem resolution, students not only develop solutions collaboratively within a team, they also share and discuss solutions across teams online. This greatly increases the diversity of solutions a learner can access with very little additional costs. In solution evaluation, the instructor's evaluation is complemented with students' voting to select the best solution considering that there are often many correct solutions (see Table 3).

Table 3. Comparing ISPS with and without online co-creation

ISPS phase	**ISPS without co-creation**	**Additional ISPS activity with co-creation**	**Role of IT in co-creation**	**Co-creation principle enacted**
Definition of problem	The instructor determines solution evaluation criteria	Students also generate and select additional solution evaluation criteria	- Online idea generation - Online voting	Decision co-creation
Resolution of problem	Students develop solution within a team	- Students are given access to other teams' solution - Students also discuss and suggest refinements to solutions proposed by other teams	Online discussion	- Solution sharing - Solution co-creation
Evaluation of solution	The instructor evaluates solutions	Students also vote to select the best solution	Online voting	Decision co-creation

3. Research model and hypotheses

This study proposes that online co-creation enhances the learning effectiveness of ISPS. Online co-creation emphasizes solution co-creation, decision co-creation, and solution sharing. Jonassen (1997) suggests that they are likely to enhance cognitive learning and epistemic cognitive learning. The hypotheses are depicted in Figure 1 and justified in detail next.

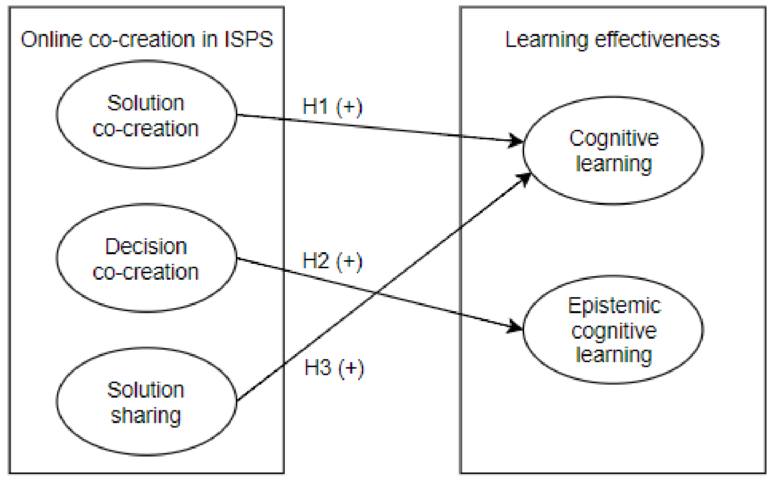

Figure 1. Model of co-creation in ISPS and hypotheses

Solution co-creation adds to the typical ISPS by allowing students to discuss and suggest refinements to solutions *across* teams online, rather than just within a team. We hypothesize that the more a student discusses and refines other solutions online, the more deeply the student learns about the subject topic (i.e., cognitive learning). This hypothesis is reasoned as follows. First, based on social constructivism, the social interaction and negotiation involved in the solution co-creation process requires one to examine the understanding embodied in other solutions. This serves as a mechanism for enriching one's understanding of the subject topic beyond that gained when developing one solution within a team (Savery and Duffy 1995). Second, as one's solution is challenged by others, the alternative views serve as a source of cognitive dissonance that stimulates further learning as one works to resolve it (Savery and Duffy 1995). Third, the persistence and asynchronicity of online discussions allow a learner more opportunity to participate in the discussion than when the discussions occur offline (Hew et al. 2010). One could keep up with a discussion at own pace and time. In sum, online solution co-creation enhances learning by extending cognitive resources to accomplish something that is difficult to achieve within a single team. Accordingly, we hypothesize the effect of cross-team solution co-creation on learning effectiveness, as follows:

H1: Online solution co-creation is positively related to cognitive learning.

Unlike the typical ISPS, decision co-creation empowers students to collectively influence key decisions of ISPS, i.e., evaluation criteria and the best solution (Papinczak et al. 2007). We hypothesize that allowing students to co-create key decisions online enhances epistemic cognitive learning, which focuses on the criteria of knowing, the certainty of knowing, and limits of knowing (Kitchner 1983). This hypothesis is based on two reasons. First, selecting and voting for the most appropriate evaluation criteria and the best solution put the learner in the position of to consider how solutions should be evaluated. This stimulates the learner to reflect and move through a development trajectory of epistemic cognition. The trajectory begins with “an absolutist or dualist view where knowledge is viewed as either right or wrong and where it is possible to know what is right with certainty. This is followed by a period of multiplicity where multiple conflicting views are acknowledged and accepted as equally valid. Finally, a more evaluativistic perspective develops where individuals acknowledge that there is no absolutely certain knowledge but still believe it is possible to evaluate competing knowledge claims and justify claims through the use of supporting evidence” (Ferguson et al. 2012, p. 104). In line with this, Lombardi et al. (2016) argue that explicit plausibility judgment, i.e., purposeful evaluation of the potential truthfulness of explanations, enhances epistemic cognition. Second, having online access to other learners’ evaluation criteria and justification for voting enhances epistemic cognitive learning further by going beyond one’s beliefs and enriching epistemic cognition. Compared to offline voting which tends to be concurrent and co-located for logistic convenience, the online environment allows a learner to take as much time as necessary to navigate through the development trajectory of epistemic cognitive learning. In sum, online decision co-creation empowers students to decide the criteria of knowing and stimulate reflection on the limits of knowing and certainty of knowing.

H2: Online decision co-creation is positively related to epistemic learning.

Solution sharing in ISPS emphasizes the accessibility of multiple solutions developed by different teams. Unlike solution co-creation, which focuses on the deep understanding of different solutions, solution sharing is concerned with accessing many various solutions of an ill-structured problem. We hypothesize that the greater number of solutions a learner accesses, the greater the extent of cognitive learning (i.e., knowledge about a subject topic). This hypothesis is based on the cognitive flexibility theory, which focuses on facilitating knowledge acquisition by providing multiple representations or perspectives on the content and presenting different approaches to solve a problem because there is often no single objective reality (Spiro 1988). Having access to multiple solutions enriches learning by confronting the problem’s complexity and avoid oversimplifying the phenomenon. This exposes a learner to a wider variety of knowledge that might not have been accessed when working within a team and the diversity broadens one’s cognitive learning. Online sharing of solutions by all the teams allows a learner to access the solutions anytime, anywhere outside class contact hours. Thus, compared to offline sharing, this greatly increases the opportunity available to a learner to benefit from the variety of solutions created.

H3: Online solution sharing is positively related to cognitive learning

There is a lack of theoretical rationale for hypothesizing that solution co-creation (i.e., discussion of particular solutions online) and solution sharing (i.e., providing access to many alternative solutions) are related to epistemic cognitive learning (e.g., criteria of knowing), and for expecting decision co-creation (i.e., voting for the best solution) to influence cognitive learning (e.g., knowledge of a subject topic). In the data analysis, we control for these relationships to rule out unexpected relationships in the proposed model.

4. Research method

To assess the proposed model, we surveyed students in one undergraduate- and two graduate- level classes, in which an online co-creation platform for ISPS was provided. To ensure adequate variance in the constructs (e.g., extent of decision co-creation), the use of the platform was voluntary and optional. Students were given information about the platform's functionality, online co-creation activities, and were regularly encouraged to participate in solution co-creation, decision co-creation, and solution sharing, but it was made clear that participation is voluntary and does not affect their grades in anyway. The development of survey instrument, data collection procedures, and sample demography are detailed next.

4.1. Survey instrument

The survey instrument was developed based on existing scales as much as possible. In cases where no suitable scale is available, we developed items based on conceptual description of the construct in seminal publications. The items measuring each construct are listed in Table 4. The items measuring solution co-creation and decision co-creation were developed based on existing scales, adapted following their conceptual description in a study of idea co-creation and decision co-creation in new product development (Pee 2016). Items for solution sharing were developed based on its conceptual description in a study of mutually beneficial relationships in value co-creation (Vargo et al. 2008), while the items for cognitive learning and epistemic learning were developed based on their conceptualization by Kitchner (1983). The initial instrument was pretested and refined in a pilot survey of 40 students before it is used to collect data.

Table 4. Survey Instrument

Construct and definition	**Items**	**Source**
Solution co-creation: The extent to which learners jointly develop solutions across teams through online social interactions	SC1: I had deep discussion of solutions proposed by other teams online*. SC2: I made effort to discuss solutions proposed by other teams online. SC3: I spent time to discuss solutions proposed by other teams. *All items rated on a seven-point Likert scale anchored by "not at all" – "very much"	Developed based on the concept of idea co-creation (Pee 2016) and the scale of participation in co-creation (Chan, Yim, and Lam 2010)

Table 4. Survey Instrument

Construct and definition	Items	Source
Decision co-creation: The extent to which learners make key decisions regarding the evaluation criteria and the best solution through online voting	DC1: I participated in the suggestion of evaluation criteria online*. DC2: I participated in the voting of evaluation criteria online. DC3: I participated in the voting of the best solution online. *All items rated on a seven-point Likert scale anchored by "not at all" – "very much"	Developed based on the concept of decision co-creation (Pee 2016) and the scale of co-decision (Barrutia and Echebarria 2012)
Solution sharing: The extent to which co-created solutions are accessible online to all participants for their benefit	SS1: I accessed (none of – many of – all of) the solutions posted by other teams online. SS2: I accessed a (narrow - wide) variety of solutions posted by other teams online. SS3: I accessed (none of – many of – all of) the information related to solutions (e.g., justification, comments) posted by other teams online.	Developed based on the concept of mutually beneficial relationships in value co-creation (Vargo et al. 2008)
Cognitive learning: understanding of knowledge related to a problem (Kitchner 1983)	CL1: I understand the knowledge needed to solve the problem CL2: I am able to explain our solution to the problem CL3: I am able to justify our solution to the problem *All items rated on a seven-point Likert scale anchored by "strongly disagree" – "strongly agree	Developed based on the concept of cognitive learning (Kitchner 1983)
Epistemic cognitive learning: criteria of knowing, the certainty of knowing, and limits of knowing related to a problem (Kitchner 1983)	EL1: I am able to identify appropriate evaluation criteria for another problem related to this topic in future. EL2: I am able to determine whether knowledge related to our solution is certain or tentative. EL3: I am able to identify the limitations of our solution to the problem. *All items rated on a seven-point Likert scale anchored by "strongly disagree" – "strongly agree"	Developed based on the concept of epistemic cognition (Kitchner 1983)

4.2. Data collection

Data for assessing the relationship between online co-creation and learning effectiveness were collected in a survey, which measured students' perceptions about the extent of online co-creation and their beliefs about cognitive and epistemic cognitive learning. The survey was conducted two weeks after the end of an ISPS assignment (see timeline in Figure 2). Students were given five weeks to develop a solution within a team and submit a written report to explain and justify the solution. One week after the assignment was announced, students were encouraged to suggest evaluation criteria and vote to select the most appropriate criteria (i.e., decision co-creation) using the online platform created based on Blackboard learning management system (henceforth Blackboard). Students were instructed to submit each suggestion to a Blackboard discussion forum as a new thread, and vote using a Blackboard survey. The two most-voted criteria was added to those pre-determined by the instructor. After the assignment deadline, all solutions were posted in a discussion forum on the online platform (i.e., solution sharing) and students were encouraged to comment on and discuss the solutions proposed by other teams (i.e., cross-team solution co-creation). They were also invited to vote to select the best solution (i.e., decision co-creation) by completing a Blackboard survey. Students were not allowed to vote for themselves. After the most-voted solution was announced, students were invited to participate in the survey measuring their perceptions about online co-creation and learning. Participation in the online co-creation activities and the survey was voluntary and not related to grades in anyway. In all the online co-creation activities, students had the option of participating anonymously. For example, they could choose to comment on a solution anonymously. A total of 320 students were invited to participate in the survey, and 225 students completed it, resulting in a response rate of 70.3%.

To illustrate, an ill-structured problem addressed by students in our sample is "How should company X adopt open innovation in its knowledge management strategy?" The problem is posed to graduate-level students studying the topic of knowledge management strategies in a public university in Singapore. Open innovation was an emerging strategy and was not covered in lectures. To address this problem, students needed to learn about the concepts of open innovation, knowledge management strategy, and the company's business domain, at least. This type of problem is often addressed in practice by strategic decision makers, who need to constantly keep up with new developments in knowledge management practices. The problem has multiple solutions and evaluation criteria. Solutions could vary depending on the type of open innovation considered and how it is incorporated into company X. The evaluation criteria could vary from short-term performance indicators (number of new product ideas) to long-term indicators (company reputation) and from intermediate indicators (e.g., innovative capability) to downstream indicators (product newness).

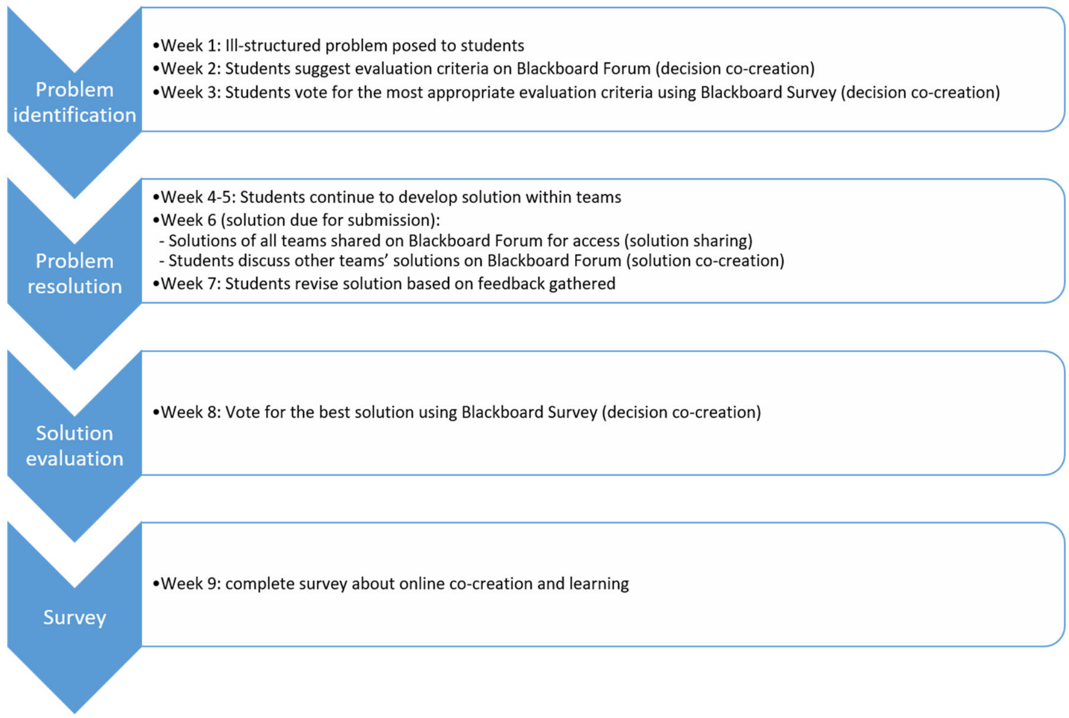

Figure 2. Timeline of study activities

4.3. Sample demography

About half of the respondents were between 21 to 22 years old (44%; see Table 5). There were more female respondents (78.2%) than male. About two thirds were undergraduate students (67.6%) in their first year of study (68%). About half of them worked in teams of four members (56.4%). All of them had used blackboard for more than 6 months. These demographic variables were controlled for in the data analysis, as detailed next.

Table 5. Sample Demography

Characteristic	Frequency	Percentage*	Characteristic	Frequency	Percentage*
Age			*Level of study*		
21	49	21.8	Undergraduate	152	67.6
22	50	22.2	Graduate	73	32.4
23	39	17.3	*Year of study*		
24	45	20.0	1	153	68.0
25-30	36	16.0	2	60	26.7
>30	6	2.7	3	8	3.6
Gender			4	4	1.8
Female	176	78.2	*Team size*		
Male	49	21.8	2	20	8.9
*Sum might not be exactly 100% due to rounding			3	48	21.3
			4	127	56.4
			5	22	9.8

5. Data analysis and results

The sample's demography was first analyzed, followed by tests of the proposed model and hypotheses. The proposed model was assessed using the partial least squares (PLS) approach of structural equation modelling because epistemic cognitive learning is a formative construct. In the model analysis, we controlled for the effects of demographic variables as well as other factors that could affect learning effectiveness: age, gender, year of study, level of study (undergraduate or graduate), team size, prior knowledge on the subject topic, and personal interest in the subject topic. Prior knowledge was measured with the item "I have knowledge relevant to solving the problem prior to joining this course", while personal interest was measured with "I am personally interested in the subject topic".

5.1. Partial least squares analysis – tests of measurement model

The measurement model was tested for reliability, convergent validity, and discriminant validity (Wetzels et al. 2009). To evaluate reliability, Cronbach's alpha and composite reliability were calculated. We found that all the values exceeded the requirement of 0.70 (see Table 6). Convergent validity was assessed by calculating average variance extracted (AVE). All the AVEs exceeded the recommended value of 0.50. Discriminant validity was assessed by examining square root of AVE. For all the constructs, the square root of AVE (italic, diagonal entries in Table 7) exceeded corresponding correlations with other constructs (non-diagonal entries in Table 7). Additional support for discriminant validity comes through inspection of the cross loadings, which were low compared with the loadings. For the formative construct of epistemic cognitive learning, these tests were not applicable. Instead, significance of item weight was examined to determine the contribution of items constituting the construct. The results were favorable, with all the item weights significant at $p<0.05$. Multi-collinearity among items was assessed using variance inflation factor (VIF). All exogenous constructs had VIF that was less than 1.97, below the recommended threshold of 3.33. Overall, the measurement model was satisfactory.

Table 6. Assessment of Reliability and Convergent Validity

Construct	Item	Loading*	Construct	Item	Loading*
Solution co-creation (SC) α=.84; CR=.91; AVE=.76	SC1	0.88	Cognitive learning (CL) α=.89; CR=.93; AVE=.81	CL1	0.90
	SC2	0.88		CL2	0.91
	SC3	0.85		CL3	0.90
Decision co-creation (DC) α=.75; CR=.86; AVE=.67	DC1	0.82	**Formative Construct**	**Item**	**Weight^**
	DC2	0.88	Epistemic cognitive learning (EL)	EL1	0.62
	DC3	0.75		EL2	0.27
Solution sharing (SS) α=.87; CR=.92; AVE=.80	SS1	0.79		EL3	0.36
	SS2	0.94	α: Cronbach's Alpha; CR: Composite Reliability; AVE: Average Variance Extracted; * All item loadings were significant at p<0.001; ^All item weights were significant at p<0.05		
	SS3	0.94			

Table 7. Descriptive Statistics, Correlations, and Discriminant Validity

Construct	Mean	SD	SC	DC	SS	CL	EL
Solution co-creation	4.91	0.75	*0.87*				
Decision co-creation	5.26	0.88	0.32	*0.82*			
Solution sharing	5.76	1.45	0.15	0.04	*0.89*		
Cognitive learning	4.85	0.61	0.45	0.33	0.18	*0.90*	
Epistemic cognitive learning	5.09	0.69	0.24	0.41	0.03	0.45	*N.A.*

5.2. Partial least squares analysis – tests of structural model

The hypotheses were tested in the structural model analysis (see Table 8). The test of hypotheses indicates that students who participated more actively in solution co-creation developed better understanding of the subject topic of the ISP (i.e., cognitive learning; H1 was supported; see Figure 3). In contrast, solution co-creation did not have a significant effect on epistemic learning. Students who participated more in deciding the evaluation criteria and the best solution (i.e., decision co-creation) understood criteria of knowing, limits of knowing, and the certainty of knowing better (i.e., epistemic learning; H2 was supported). Unexpectedly, decision co-creation is also significantly related to cognitive learning. Students who participated more in solution sharing also developed better understanding of the subject topic by accessing solutions proposed by other teams (i.e., cognitive learning; H3 was supported). In contrast, solution sharing did not have a significant effect on epistemic learning. The model explained 29.3% of the variance in cognitive learning and 24.5% of the variance in epistemic learning. Among the control variables, the level of study affected both cognitive and epistemic learning, while interest in topic affected only cognitive learning.

Table 8. Results of Hypothesis Tests

	Cognitive learning			Epistemic cognitive learning			Result
Hypothesis	**Path Coefficient**	**T Statistic**	**P Value**	**Path Coefficient**	**T Statistic**	**P Value**	
Age	-0.05	0.49	0.621	0.08	0.78	0.437	Among the control variables, level of study affects both cognitive and epistemic learning, while interest in topic affects cognitive learning only
Gender	0.01	0.19	0.852	-0.03	0.41	0.685	
Year of study	-0.01	0.41	0.685	0.00	0.02	0.985	
Prior knowledge on topic	-0.01	0.25	0.804	-0.01	0.22	0.825	
Team size	-0.06	1.11	0.266	-0.13	1.83	0.068	
Level of study	0.17*	2.09	0.036	-0.19*	2.19	0.029	
Interest in topic	0.12*	2.11	0.035	0.11	1.62	0.106	
Solution co-creation	0.37***	4.11	<0.001	0.14	1.30	0.194	H1 is supported
Decision co-creation	0.24**	2.97	0.003	0.36***	3.90	<0.001	H2 is supported
Solution sharing	0.16*	2.19	0.029	0.01	0.08	0.932	H3 is supported

*p<0.05; **p<0.01; ***p<0.001

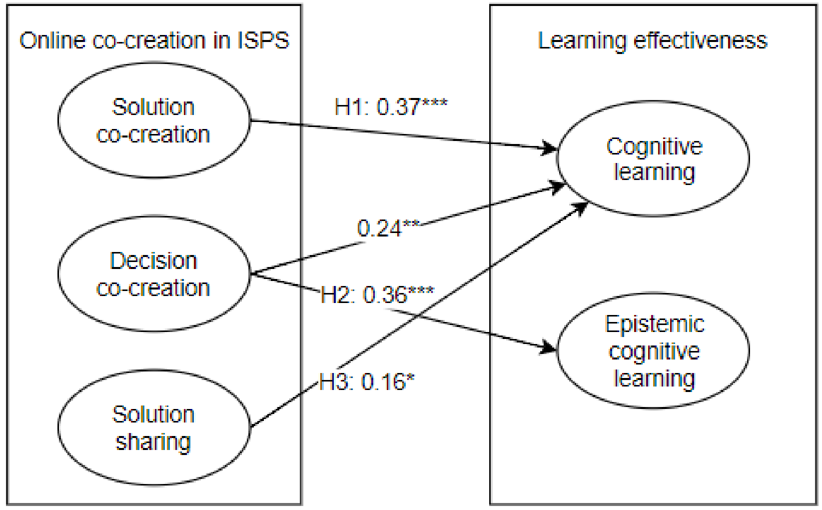

Figure 3. Significant relationships in the test of structural model

6. Discussion

This study proposes that online co-creation improves the learning effectiveness of ISPS by leveraging its multiplicity. We addressed the research question: How does online co-creation affect the learning effectiveness of ill-structured problem solving? Results of our survey support the proposed model, which captures different aspects of online co-creation and learning effectiveness. Specifically, cross-team solution co-creation and solution sharing increase cognitive learning, while decision co-creation enhances epistemic learning. Unexpectedly, we found that decision co-creation also increases cognitive learning. These findings and the study's limitations are discussed next, followed by the findings' implications for further research and practice.

This is the first empirical study to show that online co-creation, comprising solution co-creation, decision co-creation, and solution sharing, increases learning effectiveness in a course. This responds to researchers' recent call for more studies that measure how online co-creation may impact the benefits of students in higher education (Dollinger et al. 2018). The three aspects of online co-creation identified and the corresponding survey scales validated in this study can serve as a basis for more research on how it affects the learning effectiveness of other learning approaches.

Unexpectedly, we observed that decision co-creation also significantly affected cognitive learning, even though the hypothesized effect on epistemic learning remains stronger. Follow-up interviews of 13 students indicate that one plausible explanation is that thinking about evaluation criteria drives students to deliberate more about the problem as well as subject topic. A student commented during an interview that participation in decision co-creation prompted him to find out more about the problem, subject topic, and stakeholders:

> *"I realized that, to come up with appropriate evaluation criteria, we need to understand the problem first. We need to know what the key concepts are, know who face the problem, and imagine their situation… like what are their indicators of success or failure? I had to read about topics that are outside the scope of this course because it seemed necessary to know them to solve the problem adequately."*

This suggests that it might be useful to identify factors mediating the effects of decision co-creation to better understand the different mechanisms through which it affects cognitive learning and epistemic learning.

This study has several limitations that should be taken into consideration when interpreting the findings. First, our findings are based on a specific sample and their generalizability should be further established with different samples, varying in cohorts, subjects, courses, universities, etc. Second, online co-creation was implemented in this study with Blackboard's basic functions, such as Forums and Surveys. More studies are needed to assess whether online co-creation remains effective when other learning management systems are used. Third, the concept of co-creation is still emerging and new principles could surface as it develops over time. Our proposed model of online co-creation in ISPS is therefore not cast in stone and is subject to change to incorporate new co-creation principles.

6.1. Implications for research and theoretical development

This study has several implications for theoretical development and research. First, this study contributes to research on ISPS in learning by proposing that the multiplicity of ISPS can be *leveraged* to improve learning effectiveness through online co-creation. This addresses a gap in research on ISPS in learning, which has mostly focused on prescribing the process of ISPS (e.g., learning strategies and curriculum designs) or assessing its learning effectiveness (Hallinger and Bridges 2017; Yew and Goh 2016), rather than how multiplicity can be managed to benefit learning, which is the key purpose of ISPS. Three aspects of online co-creation were identified based on the principles of co-creation, namely, solution co-creation, decision co-creation, and solution sharing. This study showed that they influence cognitive learning and epistemic learning differently. The proposed model captures the learning effectiveness of online co-creation in ISPS. The model's validity can be further established by testing it in different contexts, such as other cohorts, subjects, courses, universities, or technology platform.

Second, this is one of the earliest studies to provide empirical evidence for the significance of online co-creation in enhancing the learning effectiveness of ISPS. This indicates that it might be fruitful to develop and understand online co-creation further. For example, can online co-creation go beyond cross-team solution co-creation, decision co-creation, and solution sharing to support learning in ISPS in other ways? Does online co-creation apply to a wide variety of contexts and students? If not, what are the boundary conditions or moderating factors? Is online co-creation useful for other collaborative pedagogical approaches, such as peer tutoring? Our conceptualization of online co-creation and the validated scales can be used or adapted for these inquiries.

Third, this study has demonstrated how online co-creation can be realized with readily available technologies that many students are likely to be already familiar with. Solution co-creation, decision co-creation, and solution sharing would have been very cumbersome, if not impossible, to implement without Internet technologies. Implementing them offline would require all learners to be collocated. Learners would have to take turn to speak in discussions within a limited time, and the number of solutions or evaluation criteria that could be discussed is also likely to be much more limited in the offline setting. Technology offers unique affordances that supports learning and this study seeks to inspire more studies on how existing technology can advance well-established learning approaches such as cooperative learning (Davis et al. 2018).

6.2. Implications for practice

For course instructors, this study demonstrated one way of implementing online co-creation in Blackboard with commonly used functions, which is one of the top three learning management systems worldwide. Solution co-creation and solution sharing can be implemented using Blackboard's Forums, with each discussion thread representing a different team's solution and students can post their comments or questions by replying to a thread. Decision co-creation can be implemented with forums and surveys. Students can submit each suggestion for evaluation criteria to a new thread in a forum. After the suggestion period, a survey can be conducted to collect their votes for the best suggestion. These functions are common and can also be implemented with other learning management systems.

7. References

Barrutia, J.M. and Echebarria, C. 2012. "Greening Regions: The Effect of Social Entrepreneurship, Co-Decision and Co-Creation on the Embrace of Good Sustainable Development Practices," *Journal of environmental planning and management* (55:10), pp. 1348-1368.

Bruffee, K.A. 1993. *Collaborative Learning: Higher Education, Interdependence, and the Authority of Knowledge*. ERIC.

Bryson, J., Sancino, A., Benington, J., and Sørensen, E. 2017. "Towards a Multi-Actor Theory of Public Value Co-Creation," *Public Management Review* (19:5), pp. 640-654.

Cheng, C.K., Paré, D.E., Collimore, L.-M., and Joordens, S. 2011. "Assessing the Effectiveness of a Voluntary Online Discussion Forum on Improving Students' Course Performance," *Computers & Education* (56:1), pp. 253-261.

Collins, R.H., Sibthorp, J., and Gookin, J. 2016. "Developing Ill-Structured Problem-Solving Skills through Wilderness Education," *Journal of Experiential Education* (39:2), pp. 179-195.

Davis, D., Chen, G., Hauff, C., and Houben, G.-J. 2018. "Activating Learning at Scale: A Review of Innovations in Online Learning Strategies," *Computers & Education* (125), pp. 327-344.

Dollinger, M., Lodge, J., and Coates, H. 2018. "Co-Creation in Higher Education: Towards a Conceptual Model," *Journal of Marketing for Higher Education* (28:2), pp. 1-22.

Fagerstrom, A. and Ghinea, G. 2013. "Co-Creation of Value in Higher Education: Using Social Network Marketing in the Recruitment of Students," *Journal of Higher Education Policy and Management* (35:1), pp. 45-53.

Ferguson, L.E., Bråten, I., and Strømsø, H.I. 2012. "Epistemic Cognition When Students Read Multiple Documents Containing Conflicting Scientific Evidence: A Think-Aloud Study," *Learning and Instruction* (22:2), pp. 103-120.

Füller, J., Mühlbacher, H., Matzler, K., and Jawecki, G. 2009. "Consumer Empowerment through Internet-Based Co-Creation," *Journal of Management Information Systems* (26:3), pp. 71-102.

Grönroos, C. 2011. "Value Co-Creation in Service Logic: A Critical Analysis," *Marketing Theory* (11:3), pp. 279-301.

Hallinger, P. and Bridges, E.M. 2017. "A Systematic Review of Research on the Use of Problem-Based Learning in the Preparation and Development of School Leaders," *Educational Administration Quarterly* (53:2), pp. 255-288.

Hew, K.F., Cheung, W.S., and Ng, C.S.L. 2010. "Student Contribution in Asynchronous Online Discussion: A Review of the Research and Empirical Exploration," *Instructional science* (38:6), pp. 571-606.

Jonassen, D.H. 1997. "Instructional Design Models for Well-Structured and Ill-Structured Problem-Solving Learning Outcomes," *Educational Technology Research and Development* (45:1), pp. 65-94.

Jonassen, D.H. 2010. *Learning to Solve Problems: A Handbook for Designing Problem-Solving Learning Environments*. Routledge.

Kitchner, K.S. 1983. "Cognition, Metacognition, and Epistemic Cognition," *Human development* (26:4), pp. 222-232.

Lee, A.R. and Kim, K.K. 2018. "Customer Benefits and Value Co-Creation Activities in Corporate Social Networking Services," *Behaviour & Information Technology* (37:7), pp. 675-692.

Lombardi, D., Nussbaum, E.M., and Sinatra, G.M. 2016. "Plausibility Judgments in Conceptual Change and Epistemic Cognition," *Educational Psychologist* (51:1), pp. 35-56.

Marco, G. and Daniele, D. 2014. "Theory of Value Co-Creation: A Systematic Literature Review," *Managing Service Quality: An International Journal* (24:6), pp. 643-683.

Marra, R.M., Jonassen, D.H., Palmer, B., and Luft, S. 2014. "Why Problem-Based Learning Works: Theoretical Foundations," *Journal on Excellence in College Teaching* (25).

McGill, I. and Beaty, L. 2001. *Action Learning: A Guide for Professional, Management & Educational Development*. Psychology Press.

Nespor, J. 1987. "The Role of Beliefs in the Practice of Teaching," *Journal of curriculum studies* (19:4), pp. 317-328.

Papinczak, T., Young, L., Groves, M., and Haynes, M. 2007. "An Analysis of Peer, Self, and Tutor Assessment in Problem-Based Learning Tutorials," *Medical Teacher* (29:5), pp. e122-e132.

Payne, A., Storbacka, K., and Frow, P. 2008. "Managing the Co-Creation of Value," *Journal of the Academy of Marketing Science* (36:1), pp. 83-96.

Pee, L.G. 2016. "Customer Co-Creation in B2C E-Commerce: Does It Lead to Better New Products?," *Electronic Commerce Research* (16:2), pp. 217-243.

Prahalad, C.K. and Ramaswamy, V. 2004. "Co-Creation Experiences: The Next Practice in Value Creation," *Journal of Interactive Marketing* (18:3), pp. 5-14.

Ramaswamy, V. and Ozcan, K. 2018. "What is Co-Creation? An Interactional Creation Framework and Its Implications for Value Creation," *Journal of Business Research* (84), pp. 196-205.

Reed, S.K. 2016. "The Structure of Ill-Structured (and Well-Structured) Problems Revisited," *Educational Psychology Review* (28:4), pp. 691-716.

Savery, J.R. 2015. "Overview of Problem-Based Learning: Definitions and Distinctions," *Essential readings in problem-based learning: Exploring and extending the legacy of Howard S. Barrows* (9), pp. 5-15.

Savery, J.R. and Duffy, T.M. 1995. "Problem Based Learning: An Instructional Model and Its Constructivist Framework," *Educational technology* (35:5), pp. 31-38.

Schmidt, H.G. 1983. "Problem ‐ Based Learning: Rationale and Description," *Medical education* (17:1), pp. 11-16.

Spiro, R.J. 1988. "Cognitive Flexibility Theory: Advanced Knowledge Acquisition in Ill-Structured Domains. Technical Report No. 441,").

Stevenso, B., Länsitie, J., Kogler, C., and Bauer, P. 2015. "Exploring Co-Creation of Educational Videos in an International Collaborative Context," *Journal of E-Learning and Knowledge Society* (11:2), pp. 63-72.

Thatcher, J., Alao, H., Brown, C.J., and Choudhary, S. 2016. "Enriching the Values of Micro and Small Business Research Projects: Co-Creation Service Provision as Perceived by Academic, Business and Student," *Studies in Higher Education* (41:3), pp. 560-581.

Trencher, G., Terada, T., and Yarime, M. 2015. "Student Participation in the Co-Creation of Knowledge and Social Experiments for Advancing Sustainability: Experiences from the University of Tokyo," *Current Opinion in Environmental Sustainability* (16), pp. 56-63.

Vargo, S.L., Maglio, P.P., and Akaka, M.A. 2008. "On Value and Value Co-Creation: A Service Systems and Service Logic Perspective," *European Management Journal* (26:3), pp. 145-152.

Wetzels, M., Odekerken-Schroder, G., and Van Oppen, C. 2009. "Using PLS Path Modeling for Assessing Hierarchical Construct Models: Guidelines and Empirical Illustration," *MIS Quarterly* (33:1), pp. 177-195.

Yang, T.-C., Chen, M.C., and Chen, S.Y. 2018. "The Influences of Self-Regulated Learning Support and Prior Knowledge on Improving Learning Performance," *Computers & Education* (126), pp. 37-52.

Yew, E.H.J. and Goh, K. 2016. "Problem-Based Learning: An Overview of Its Process and Impact on Learning," *Health Professions Education* (2:2), pp. 75-79.