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SPECIAL ISSUE ON COMPETENCY ORIENTATION IN PROBLEM-BASED LEARNING

How to Enhance Interdisciplinary Competence—Interdisciplinary Problem-Based Learning versus Interdisciplinary Project-Based Learning

Mirjam Brassler (University of Hamburg) and Jan Dettmers (Medical School Hamburg)

Abstract

Interdisciplinary competence is important in academia for both employability and sustainable development. However, to date, there are no specific interdisciplinary education models and, naturally, no empirical studies to assess them. Since problem-based learning (PBL) and project-based learning (PjBL) are learning approaches that emphasize students' collaboration, both pedagogies seem suitable to enhance students' interdisciplinary competence. Based on the principle of constructive alignment and four instructional principles on interdisciplinary learning, this paper proposes that students profit more from interdisciplinary PBL (iPBL) than interdisciplinary PjBL (iPjBL). A pre-post study was conducted with a sample of 95 students participating in iPBL and 183 students participating in iPjBL. As expected, multilevel models on students' development in (a) interdisciplinary skills, (b) reflective behavior, and (c) recognizing disciplinary perspectives show that iPBL enhances students' interdisciplinary competence more than iPjBL.

Keywords: interdisciplinary competence, interdisciplinary learning, problem-based learning, project-based learning, PBL, PjBL

Introduction

Interdisciplinary teaching and learning in higher education institutions has been identified as key to twenty-first century education (Khadri, 2014; Kolmos, 2016). Some even advocate interdisciplinarity as a logical next step toward a post-disciplinary stage of education (Frodeman, 2014). Twenty-first century skills are defined as critical thinking and problem solving; communication; collaboration and team building; and creativity and innovation (P21, 2012). At the university level, these skills are highly aligned with interdisciplinarity, which is defined as "a means of solving problems and answering questions that cannot be satisfactorily addressed using single methods or approaches" (Klein, 1990, p. 196). To successfully engage in interdisciplinarity—more precisely, to be able to understand and act in any given interdisciplinary learning or work situation—students need adequate personal and social skills, referred to as interdisciplinary competence, that highly relate to each of the twenty-first century skills. These are: taking a critical stand on disciplinary limitations, solving complex problems across disciplines, communicating across disciplines, handling interdisciplinary collaboration and teamwork, as well as using integrative potentials to create innovations (Brandstädter & Sonntag, 2016; Lattuca, Knight, & Bergom, 2013; Pecukonis, Doyle, & Bliss, 2008; Shen, Sung, & Zhang, 2015).

According to Kolmos, Hadgaft, and Holgaard (2016), nowadays there are three modes for universities to consider. First, there is the academic mode, aiming for knowledge and theory education. Second, there is the market-driven innovation mode, aiming toward employability. Third, there is the hybrid learning and responsibility mode, aiming toward critical consciousness regarding the sustainability development goals. Interdisciplinary competence addresses all of these three modes. (I) Regarding the academic mode, interdisciplinary competence promotes a holistic view on theory and knowledge development. Moreover, interdisciplinary science teams are becoming more prevalent in academia (Foire,

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2008). Hence, interdisciplinary education promoting interdisciplinary competence goes in line with up-to-date scholastic training in academia. (II) Regarding the market-driven mode, one should consider organizations' increased interest in interdisciplinary competence, since projects and tasks for the future workforce are becoming more complex (Frodeman, 2014; Newell, 2010). Moreover, interdisciplinarity is highly associated with innovation (Harrison & Klein, 2007). (III) In line with the hybrid learning and responsibility mode, a development of students' interdisciplinary competence is needed to address urgent problems regarding sustainability, also called the "grand challenges" of our time (Frodeman, 2014). These complex problems cannot be solved within one discipline (Schmidt, 2008). Therefore, it is essential that universities support students' abilities to collaborate across disciplines, hence facilitating interdisciplinary competence. This paper addresses the question of which pedagogy is suitable to develop interdisciplinary competence, aiming toward recommendations for universities' curriculum design.

Research into teaching and learning in interdisciplinary higher education was found to be limited and explorative (Spelt, Biemans, Tobi, Luning, & Mulder, 2009). Specific interdisciplinary education models and corresponding empirical data are missing (Woods, 2007). It has been suggested that adding interdisciplinarity to PBL and PjBL has the potential to strengthen students' collaborative skills (Hmelo-Silver, 2012; Imafuku, Kataoka, Mayahara, Suzuku, & Saiki, 2014; Jonassen, 2011). Both pedagogies are learning approaches that emphasize students' collaboration in providing an authentic application of content and skills, while aiming for a development of twenty-first century skills (Larmer, 2014; Perrenet, Bouhuijs, & Smits, 2000; Savery, 2006). Since research on competence development in PBL and PjBL is lacking clarity on elements of educational design (Dole, Bloom, & Kowalske, 2016; Kolmos, 2016), this paper outlines similarities and differences of both pedagogies to investigate the following research question: which pedagogy is more suited to facilitate the development of interdisciplinary competence—iPBL or iPjBL?

iPBL versus iPjBL

While PjBL was first introduced as the project method to engage students into hearty and purposeful activities by Kilpatrick (1921), further developed by Blumenfeld et al. (1991), PBL was originally developed in medical school programs (Barrows & Tamblyn, 1980) to motivate medical students with realistic problem cases. PjBL is defined as a pedagogy that entails two components that are "a question or problem that serves to organize and drive activities; and these activities result in a series of artifacts or products, that culminate in a final product that addresses the driving question" (Blumenfeld et al., 1991, p. 371). Meanwhile, PBL is defined as "a curriculum development and instructional system that simultaneously develops both problem solving strategies and disciplinary knowledge bases and skills by placing students in the active role of problem solvers confronted with an ill-structured problem that mirrors real-world problems" (Finkle & Torp, 1995, p. 1). Both pedagogies are similar in that the learning activities are organized around achieving a shared goal by emphasizing students' independence, self-direction, inquiry, and collaboration, providing an authentic application of content and skills, and focusing on open-ended questions, while aiming for a development of twenty-first century skills (Larmer, 2014; Perrenet et al., 2000; Savery, 2006). Moreover, both pedagogies are often associated with interdisciplinarity (Perrenet et al., 2000; Savery, 2006).

Research regarding PBL and PjBL is often lacking clarity on elements of educational design (Dole et al., 2016; Kolmos, 2016). Some researchers even tend to equalize both pedagogies (English & Kitsantas, 2013; Maudsley, 1999). Also, among researchers viewing both pedagogies as distinct, there is no agreed-upon definition of distinctions in regard to each characteristic, but rather a commonly accepted differentiation of focus in each pedagogy, with PBL focusing on learning itself and PjBL focusing on creating a product (Donnelly & Fitzmaurize, 2005; Helle, Tynjälä, & Olkinuora, 2006; Kolmos, 2016). Aiming toward a clear distinction of several different characteristics within both pedagogies, this paper presents an overview of literature describing either one or comparing both pedagogies. The following distinctions (see Table 1, next page) are not only fundamental to contrast outcomes in this design based research but most importantly to address challenges within an interdisciplinary approach.

Most of the mentioned literature focuses on describing monodisciplinary development and the monodisciplinary realization of PBL and PjBL. Adding an interdisciplinary approach of learning to both pedagogies makes each more complex. Interdisciplinary learning is defined as a process by which "learners integrate information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines to craft products, explain phenomena, or solve problems, in ways that would have been unlikely through single-disciplinary means" (Boix Mansilla, 2010, p. 289). Adding interdisciplinary learning to PjBL, the focus on the product now also entails an application of different information, data, techniques, tools, perspectives, and so forth toward an innovative and effective product. In contrast, PBL places the emphasis on the learning itself. Therefore, the focus is on learning about each other's different information, data, techniques, tools, perspectives, and so forth. By addressing five to six problems per semester, iPBL provides an experience in a variety of themes of each other's disciplines. However, iPjBL students might gain deeper insight into one topic

Table 1. Distinctions of (interdisciplinary) Problem-Based Learning (iPBL) and (interdisciplinary) Project-Based Learning (iPjBL).

Characteristics	(Interdisciplinary) Problem-based Learning (i)PBL	(Interdisciplinary) Project-based Learning (i)PjBL
Duration Larmer, 2014.; Park et al., 2013; Perrent et al., 2000	Rather short-term, 5–6 problems per semester	Rather long-term, 1 project per semester
Problem/Task Donnelly & Fitzmaurize, 2005; Kolmos, 2016; Larmer, 2014;	Ill-structured cases, open and narrow	Real-world, fully authentic tasks, open and narrow
Definition of Problem/Task Making core choices Kolmos, 1996; Sevary, 2006; Helle et al., 2006	(mostly) student	(mostly) teacher
Process Braßler, 2016; Donnelly & Fitzmaurize, 2005; Kolmos, 2016; Larmer, 2014	Following specific steps (1) clarifications of concepts (2) formulation of an (i) problem statement (3) (multidisciplinary) brainstorming (4) (i) structuring (5) formulation of (i) learning objectives (6) self-study (across disciplines) (7) (i) post-discussion (8) formulation of an integrative team statement	Following general, broad steps of project management (i) Task analysis, identification of (i) solutions, implementation of (i) solution
Problem solving level Kolmos, 1996	Problem analyses (rather theoretical)	Problem solving (rather practical)
Role of the teacher/tutor Donnelly & Fitzmaurize, 2005; Kolmos, 1996; Park et al., 2013; Savery, 2006	Process-oriented supervisor/facilitator	Product-oriented supervisor/ instructor
Outcome/focus/aim Donnelly & Fitzmaurize, 2005; Helle et al., 2006; Larmer, 2014; Park et al., 2013; Savery, 2006	Presentation of knowledge acquisition	"tangible" products
Assessment Braßler 2016; Kolmos, 2016	Individual & group assessment— (mostly) based on learning	Individual & group assessment— (mostly) based on product

during the completion of one project. For example, imagine a class of students from psychology and economics, taking on the interdisciplinary topic of corruption as either one problem in iPBL or one project in PjBL.

In iPBL, students could be confronted with an ill-structured case presenting three situations: political corruption in the developing country of Pakistan, business corruption at Enron USA, and petty corruption at a German university (a student providing sexual favors to a teacher in exchange for a good grade). In iPjBL, students could be assigned with the task to develop and implement a whistle-blowing agency within the student union against corruption at their university. Both problems are thematically between the involved disciplines. However, in iPBL, the teacher constructs the cases

inspired by real events; nevertheless, it remains a theoretical solution without any intention of realization. In contrast, in iPjBL, the teacher introduces a project within the real world. Over two sessions in iPBL and one semester in iPjBL the interdisciplinary student teams undergo different processes in each method. Students follow eight steps in iPBL. After reading the ill-structured case, they discuss unknown concepts and discipline-based technical terms mentioned in it; for example, the economic term "offshore" is likely not to be familiar to psychology students. Second, within the given framework, they define their interdisciplinary problem statement by integrating viewpoints across disciplines. This could range from "immoral behaviors and related costs" to "power and corruption" or "prevention of corruption." With regard to their interdisciplinary problem, they brainstorm discipline-based information, data, techniques, tools, perspectives, concepts, and theories related to their problem and collect ideas, explanations, and hypotheses for the underlying problem across psychology and economics on a pin board. Thereafter, they identify discrepancies, interrelationships, and gaps between the disciplines, for example, presuming different motivators for immoral and corrupt behaviors in economics and psychology. Next, they define interdisciplinary learning objectives by formulating questions that are relevant to the team and reflect each discipline involved. These could be: "Under which conditions does power corrupt?" or "Why do people engage in immoral behaviors?" Guided by their questions and interests, students search and read academic research papers across disciplines. For instance, a psychology student reads one psychology paper on "dark side traits" and one economics paper on "principal agent theory on corruption." Back in session, students present their gained answers and learning objectives across disciplines, and they discuss and integrate their new ideas. Finally, they formulate a team statement in regard to their interdisciplinary problem statement by integrating discipline-based information, data, theories, and related research outcomes.

In contrast, iPjBL students follow general, broad steps of project management. In the example of developing and implementing a whistle-blowing agency within the student union against corruption at their university, as a first step for the task analysis, the interdisciplinary student team would talk to the student union and gain insights regarding the problem of corruption within their university. Possible questions could be: "What kind of corruption occurred previously? In which faculties? Why? What did they previously do? What helped? What did not help? How should the whistle-blowing agency address corruption?" Within their interdisciplinary team, they discuss the viewpoint of the student union and identify tasks that are necessary to find solutions on how a whistle-blowing agency could be installed. Several tasks could be planned, distributed, and executed according to the habits of work in the involved disciplines of psychology and economics: identifying problems and needs in each faculty with interviews, gaining insight into the legal situation of corruption at universities, questioning experts through interviews (e.g., contacting an outside, anticorruption NGO and experienced stakeholders in other universities), and identifying barriers and facilitators of whistle-blowing by reading academic research from both economics and psychology. Thereafter, they identify interdisciplinary solutions, such as the implementation of an anticorruption codex and the establishment of a whistle-blowing hotline and a help desk for students. With a cost and benefit analysis including both psychological parameters, like psychological pain, and economic parameters, like reachability and monetary costs, the interdisciplinary student team decides on their action plan, gets financial support from the university, and implements their ideas.

Looking at the different processes in iPBL and iPjBL can help highlight the focus of each method. While the students in iPBL concentrate on an academic solution to their defined problem by following steps repeatedly integrating ideas after collecting discipline-based views on the problem, students in iPjBL actually solve a problem connected to the given task by keeping the final product in mind. The problem solving in iPBL is rather theoretical, while iPjBL produces an authentic, practical, "tangible" solution. While the task is predefined by the instructor in iPjBL, iPBL students use the given problem case as an incentive to define their own problem statement. Accordingly, the roles of instructors are distinct in each method. The iPBL instructor focuses on the learning processes by providing feedback in regard to team processes, interdisciplinary integration, and interdisciplinary communication, since he or she is present most of the time in the team sessions. In contrast, the iPjBL instructor focuses on the product. For example, the iPjBL tutor provides additional discipline-based information that students missed, connects students with relevant stakeholders, and supports students in gaining financial support. He or she offers guidance if conflicts in the interdisciplinary team arise to restore their capability to work toward the product. The exam is also distinct in each method. iPBL uses a group oral exam: the interdisciplinary team receives a problem to discuss (e.g., a new case of corruption), and then follows the same steps (2, 3, 4, 7, 8) as in the learning sessions. Their work in the oral exam is graded according to the quantity of mentioned papers explained by the opposite discipline (e.g., psychology student explaining an economic theory), the quality of elaboration of integrative solutions, and their reflection on limitations of their ideas. In contrast, iPjBL students are graded on the quality of their product—more precisely, their integration of approaches from all disciplines involved as well as the usability and applicability of their product.

Framework

PBL (Marra, Jonassen, Palmer, & Luft, 2014; Savery & Duffy, 1995), PjBL (Blumenfeld et al., 1991), and interdisciplinary learning (Klein, 2006) are highly associated with the constructivist philosophy, particularly the work of Piaget, Dewey, and Vygotsky (Dole et al., 2016). The constructivist philosophy focuses on learning as an active process in which the inquiry of knowledge is based on personal experiences and interactions with the environment. Humans as learners perceive the world, interpret activities, and construct knowledge through questions, tests, and answers in an iterative process. Both PBL and PjBL are student-centered pedagogies that facilitate collaborative teamwork toward an understanding and reflection of real-life, complex problems. Encountering a problem functions as an incentive or goal for learning and consequently leads to actual learning (Dewey, 1938). If the experience of new information cannot be assimilated into an existing schema, there is a need for accommodation (Piaget, 1977). Due to distinct discipline-based values, knowledge traditions, and used schemas in each scientific community (Epstein, 2005; Frost & Jean, 2003; Repko, 2008), students are confronted with different views on the world in an interdisciplinary learning environment. Students can reconstruct knowledge by reproducing knowledge from foreign disciplines, deconstruct existing knowledge by identifying one's discipline limitations, and construct knowledge by innovatively integrating ideas across disciplines (Braßler, 2016). Each disciplinary community has its own culture (Pecukonis et al., 2008) and unique set of terms within their professional language (Brewer, 1999; Jeffrey, 2003; Repko, 2008). Following Vygotsky (1978), language and culture play essential parts both in human intellectual development and in how humans perceive the world. In an interdisciplinary learning environment, students interact with members of other knowledge communities. While communicating across professional languages, students overcome their limitations of their perceptual academic fields and enrich their understanding of the world. Interdisciplinary learning allows students to co-construct knowledge across disciplinary cultures aligned with social constructivism (Vygotsky, 1978).

In line with the up-to-date educational debate on competence orientation (Ordonez, 2014), learning in iPBL and iPjBL can go beyond the construction, co-construction, and application of knowledge across disciplines and individual understanding of the world. Furthermore, interdisciplinary learning might enhance competencies "that are useful for achieving many important goals, mastering different tasks, and acting in unfamiliar situations" (Weinert, 2001a, p. 52). Competencies are defined as "combinations of those cognitive, motivational, moral, and social skills available to (or potentially learnable by) a person . . . that underlie the successful mastery through appropriate understanding and actions of a range of demands, tasks, problems, and goals" (Weinert, 2001b, p. 2433). Competencies are considered to be potentials or dispositions, enabling a person to act within a given, complex situation. An interdisciplinary learning or work environment constitutes such a complex situation, requiring necessary and adequate competencies. By confronting students with interdisciplinary problems, there is a need to not only learn about the other discipline, but also to be able to actually integrate different views and positions. Following Lattuca et al. (2013), interdisciplinary competence refers to the understanding of different disciplinary knowledge, methods, expectations, and boundaries. Further, it refers to the ability to think about different disciplinary perspectives, to use different disciplinary perspectives in solving interdisciplinary problems by making connections, to synthesize and integrate knowledge across academic fields, and the ability to recognize the need to reconsider the direction of one's thinking and problem solving approaches.

With regard to the research question of which pedagogy is more suited to facilitate the development of interdisciplinary competence, iPBL or iPjBL, one needs to answer the question of how competencies are developed best within a given learning environment. One theoretical approach combining constructivism and aligned design for outcomes-based teaching education applies here: the principle of constructive alignment (Biggs, 1996; Biggs & Tang, 2011). Teaching fulfils the principle of constructive alignment if learning objectives are competence-oriented and communicated in advance, if performance assessments measure students' achievement of learning objectives (i.e., competencies), and if learning activities help students to achieve the learning objectives (i.e., acquire competencies). While the students construct their own learning through engagement in relevant learning activities, the teacher creates appropriate learning environments. Hence, good teaching systems have a high coherence between intended learning outcomes, teaching methods, and assessments; the intended learning outcome is students' development of an interdisciplinary competence. In line with constructive alignment, to enhance students' development of interdisciplinary competence, one should choose appropriate teaching methods and assessments. Teaching methods facilitating interdisciplinary competence should thereby include activities to understand different disciplinary knowledge, methods, expectations, and boundaries; to think about different disciplinary perspectives; to use different disciplinary perspectives in solving interdisciplinary problems by making connections, and synthesizing and integrating knowledge across academic fields; and to recognize the need to reconsider the direction of one's thinking

and problem solving approaches. Similarly, the pragmatic-constructionist theory on interdisciplinary learning by Boix Mansilla (2010, 2016) addresses the question of how one can design instruction to facilitate interdisciplinary integration in an interdisciplinary learning environment. The theory presents four instructional principles in interdisciplinary learning: (1) let students establish their purpose by gaining a holistic sense of the problem space (interdisciplinary purpose); (2) help students gain disciplinary insights (disciplinary grounding); (3) facilitate synthesis (leveraging integrations); and (4) let students reflect (critical stand). Each aspect of interdisciplinary competence is addressed by these principles of instructional design. Understanding different disciplinary knowledge, methods, expectations and boundaries and thinking about different disciplinary perspectives is connected to disciplinary grounding by providing students with a deeper understanding of unfamiliar disciplines. Using different disciplinary perspectives in solving interdisciplinary problems by making connections, synthesizing and integrating knowledge across academic fields is connected to leveraging integrations by iteratively calibrating disciplinary perspectives toward integration. Recognizing the need to reconsider the direction of one's thinking and problem solving approaches is associated with a critical stand by reflecting one's learning process. Starting with an interdisciplinary purpose allows for synthesis and integration by usage of different disciplinary perspectives. According to the principle of constructive alignment, these learning activities should match the assessment. Hence, a test in iPBL or iPjBL should address the same activities as in the learning environment to allow students to show their development of each element of interdisciplinary competence.

To address the research question of which pedagogy is better at facilitating interdisciplinary competence in regard to coherent learning activities and coherent assessment, a comparison of relevant characteristics of iPBL and iPjBL is in order. With regard to the pragmatic-constructionist theory on interdisciplinary learning, one has to examine the process students follow in each pedagogy, corresponding to each of the four principles of instruction. In iPBL, students are expected to go through several steps. They must establish their purpose when formulating the interdisciplinary problem statement. They are instructed to gain disciplinary insights by clarifying concepts, brainstorming disciplinary information, reading academic papers across disciplines, and explaining gained knowledge from other disciplines in the post-discussion. Moreover, iPBL students are guided to synthesize disciplinary perspectives by defining an interdisciplinary problem statement, formulating interdisciplinary learning objectives, and creating an integrative team statement. Finally, they must reflect their direction of thinking and their problem solving approaches by structuring and discussing their ideas. Moreover, they take a critical stand after each teamwork session, jointly reflecting on their teamwork.

In contrast, iPjBL students are not directly guided toward interdisciplinary learning by including the four principles of instruction. The instructor assigns the students their projects with a product in mind. Thus, even though the instructor or teacher clearly has an implicit interdisciplinary, it is not explicitly formulated and can hence be overlooked and circumvented by the students. Moreover, iPjBL students might engage in gaining disciplinary insights, by synthesizing and reflecting, but they are not actively guided toward it. In comparison, iPBL literally guides students, step-by-step, toward gaining disciplinary insights and integrating perspectives in an iterative process.

With regard to the intended coherent assessment, one should address the same activities as in the learning sessions to allow students to show the development of each element of interdisciplinary competence. The interdisciplinary oral exam in iPBL, which follows the same steps as in the learning sessions, allows students to show their developed interdisciplinary competence in action. In contrast, in iPjBL the exam is the product; hence, students are graded with regard to the results of their actions. Even though the product indicates a degree of interdisciplinary integration, instructors cannot assess individual understanding of disciplinary perspectives, since included disciplinary information could derive from students with the same discipline. However, the latter clearly is not the purpose, since the product itself is the focal point.

Since iPjBL aims toward a tangible product, the task, as well as teachers' and tutors' behaviors and assessments, all predominantly focus on the product. In contrast, iPBL's design focuses on the learning itself. iPBL students are guided more toward students' interdisciplinary understanding and integration than in iPjBL. Moreover, since iPBL students anticipate an assessment based on their learning in an oral exam, their focus also lies on competence development. Consequently, the iPBL design is more closely linked to interdisciplinary competence development than iPjBL. This theoretical line of argument suggests that iPBL students should gain greater interdisciplinary competence than iPjBL students should.

A review by Spelt, Biemans, et al. (2009) shows that research into teaching and learning in interdisciplinary higher education is rather limited and explorative. Specific interdisciplinary education models and corresponding empirical data regarding interdisciplinary competence were found to be missing (Woods, 2007). However, a pedagogy aiming toward active learning and collaboration—as well as a learning process designed iteratively with milestones and encountering questions, reflection, and gradual advancement—is highly recommended by many authors (Manathunga, Lant, &

Mellick, 2006; Spelt, Biemens, et al., 2009; Woods, 2007). All of these recommendations could be satisfied with both iPBL and iPjBL. However, iPBL has a stronger focus on gradual steps and guiding self-defined questions. In medical education, iPBL could support the development of an appreciation of the roles of others in different disciplines (Solomon, Salvatori, & Guenter, 2003). An evaluation of a more recent iPjBL course could show an enhancement of students' awareness of disciplinary and cultural boundaries, as well as an increase in their appreciation of using different perspectives in developing sustainable solutions (Fortuin & Bush, 2010). Moreover, a qualitative evaluation of an interdisciplinary, scenario-based course indicates that students learn each other's scope of practice and build confidence in their communication skills across disciplines (Solomon & Salfi, 2011). All of these results indicate potential benefits to students who experience either one of or both pedagogies. However, so far, there is only one study that compares PBL and PjBL. Wheeler (2008) found support that PBL does generate greater perceived student–instructor interaction and increased critical thinking than PjBL does. Since taking a critical stand is highly associated with interdisciplinarity (Boix Mansilla, 2016), and the guidance of a iPBL tutor or teacher leads to a higher focus on learning, this result, again, advocates for a stronger development of interdisciplinary competence in iPBL. Consequently, we propose the hypothesis that iPBL is more suited to enhance the development of interdisciplinary competence.

Method

Sample

The included iPBL and iPjBL courses were selected because they fit the characteristics listed in Table 1. To identify courses meeting the criteria, class schedules of five universities were screened. If the course titles included "interdisciplinarity" or "interdisciplinary" and the course descriptions indicated an interdisciplinary approach including teamwork, the instructors were contacted. Additionally, program directors were contacted to gain further recommendations, since not all interdisciplinary courses actually include "interdisciplinarity" or "interdisciplinary" in the titles.

In a call or a meeting, the authors asked the instructors whether their courses met the criteria by going over each characteristic in the list. Most of the courses were excluded because their teaching methods did not include actual teamwork, or only included teamwork for a few sessions so there was no continuous teamwork in a constant composition of team members over one semester. Further, most courses were constructed with disciplines working as parallel or additive (multidisciplinary) rather than integrative (interdisciplinary) and therefore were not included in the sample.

Over two years (2013–2015), or three semesters, the authors observed 13 iPBL courses (13 teams) and 5 iPjBL courses (48 teams). All courses were visited four times during the semester. To ensure the realization was in line with the characteristics listed in Table 1, the authors observed the learning sessions and talked to instructors and students. The sample consisted of 278 participants (123 males, 44.2%, and 155 females, 55.8%) who were enrolled in either iPBL (N = 95) or iPjBL (N = 183) courses at one of three higher education institutions in northern Germany. The mean age of the participants was 24.73 years (SD = 4.21). In iPjBL, 11 interdisciplinary student teams terminated their teamwork before the end of the course. Therefore, 64 participants were excluded from the data. In regard to the prematurely terminated interdisciplinary teams, instructors and students reported escalations of conflict within the interdisciplinary teams as a reason for quitting. The interdisciplinary teams in iPBL consisted of psychology, business administration, and economics students, while the interdisciplinary teams in PjBL consisted of students in psychology, economics, pedagogics, law, linguistics, physics, informatics, environmental studies, politics, geography, and mechanical engineering. All students were in their fifth semester of studies or higher, ensuring strong discipline-specific knowledge. In both pedagogies, students remained in the same team for the duration of the semester (a little more than four months).

Course Descriptions

All courses, both iPBL and iPjBL, were realized according to the characteristics in Table 1 and executed in the same way as described in the examples above. All courses were outlined with the intended learning outcome of an enhancement in interdisciplinary competence.

iPBL students were confronted with five problem cases: "Negotiating conflicts"; "Living and working in a social market economy?!"; "Corruption"; "Healthiness in a modern working world"; and "Change in institutions, organizations, and societies." All problems represent a thematic closeness of involved disciplines. The projects in iPjBL focused on several topics, such as:

- realization of a flea market to gain money for a social cause,
- development of a policy program for several countries regarding nuclear power strategies in reflection with talks to politicians attending a UN conference,
- realization of an advisory book on sustainable nutrition,
- realization of a guerilla marketing campaign,

- realization of awareness-raising approach of adequate treatment of chronically ill patients,
- development of successful integration strategies for immigrant workers, and
- realization of an inclusive urban gardening project.

In regard to the exam, all iPBL students received a new problem case mirroring one of their previously defined problem statements during the semester, while all iPjBL students were graded on their realizations of their projects.

Design

The study was conducted with a two-group, pretest-posttest design. The two groups are the pedagogies of iPBL and iPjBL. The pretest focuses on the interdisciplinary competence of each student before taking either an iPBL or a iPjBL course, while the posttest focuses on the interdisciplinary competence of each student after participating in either an iPBL or a iPjBL course. Each student was asked to fill out a survey, which took about 10 minutes, two times: before the first teamwork session and after the last teamwork session in either iPBL or iPjBL.

Measures

In line with recent approaches to measure competencies with self-report inventories (Braun, Gusy, Leidner, & Hannover, 2008; Kuh, 2009; Schaeper, 2009), this study follows self-reported interdisciplinary competence using the scale by Lattuca et al. (2013). The scale has three components: interdisciplinary skills, reflective behavior, and recognizing disciplinary perspectives. The scale was developed in seven steps:

1. an extensive literature review on key topics in interdisciplinarity from fields of interdisciplinary studies, education, business, research management, cognitive science, philosophy, and sociology of science;
2. identification of eight dimensions of interdisciplinarity;
3. conducting interviews with focus groups in regard to curriculum development,
4. generating items based on the results of the last two steps;
5. conducting a pilot study;
6. revision; and
7. final study.

Since the scale was developed to measure interdisciplinary competencies of engineering students, items were adapted to discipline neutral items for the present study (e.g. "I value reading topics outside of engineering" was adapted into "I value reading topics outside of my discipline"). Following the translation and adaption guidelines by Hambleton and de Jong (2003), all items were translated into German and back into English, so three native speakers could compare the original and backward translation on literal and contextual equivalence with satisfying results (all over 80%). As described by Lattuca et al. (2013), interdisciplinary skills consist of items that operationalize 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 behavior scale measures the "reflexivity" dimension of interdisciplinarity, assessing students' perceived ability to recognize the need to reconsider the direction of their thinking and problem solving approaches. The recognizing disciplinary perspectives scale measures students' perceived understandings of disciplinary knowledge, methods, expectations, and boundaries, as well as how disciplinary knowledge might be applied in different situations. The interdisciplinary skills subscale consisted of 8 items (α = .72), the reflective behavior subscale consisted of 2 items (α = .79), and the recognizing disciplinary perspectives subscale consisted of 3 items (α =.69).

Results

Table 2 shows the means and standard deviations of Time 1 (before course) and Time 2 (after course) of students' interdisciplinary competence with the three components: interdisciplinary skills, reflective behavior, and recognizing disciplinary perspectives in iPBL and iPjBL. The descriptive data show an increase of all three components of interdisciplinary competence in iPBL students, while there is almost no change in iPjBL students.

Table 2. Means and standard deviations of Time 1 and Time 2 of students' Interdisciplinary Skills, Reflective Behavior, and Recognizing Disciplinary Perspectives in iPBL and iPjBL.

		Interdisciplinary Skills				**Reflective Behavior**				**Recognizing Disciplinary Perspectives**			
		Time 1		Time 2		Time 1		Time 2		Time 1		Time 2	
	N	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
iPBL	119	3.49	0.67	4.07	0.71	3.50	0.67	4.23	0.59	3.54	0.55	4.03	0.61
iPjBL	95	3.60	0.55	3.63	0.61	3.54	0.65	3.55	0.61	3.61	0.61	3.57	0.52

Table 3. Multilevel models regarding Interdisciplinary Skills, Reflective Behavior, and Recognizing Disciplinary Perspectives in iPBL and iPjBL

	Interdisciplinary Skills		**Reflective Behavior**		**Recognizing Disciplinary Perspectives**	
	B	95% CI [*LL*,*UL*]	*B*	95% CI [*LL*,*UL*]	*B*	95% CI [*LL*,*UL*]
Intercept [iPjBL]	3.61***	[3.43, 3.75]	3.54***	[3.33, 3.79]	3.60***	[3.36, 3.83]
iPBL	0.43**	[0.21, 0.65]	0.36**	[0.14, 0.58]	0.50*	[0.02, 0.88]
R^2		.81		.63		.55

Note. CI = confidence interval; *LL* = lower limit; *UL* = upper limit. $N_{iPjBL} = 37$, $N_{iPBL} = 13$. R^2 was computed following Hox (2002).
*$p < .05$. **$p < .01$.***$p < .001$.

Since each student works within a team in both pedagogies, multilevel models regarding interdisciplinary skills, reflective behavior, and recognizing disciplinary perspectives were conducted. The results are shown in Table 3.

All multilevel models show a significant difference of the pedagogies, with iPBL showing higher development in interdisciplinary skills, reflective behavior, and recognizing disciplinary perspectives than in iPjBL.

Further Analysis

The composition of interdisciplinary teams differed between iPBL and iPjBL courses. The teams in iPBL courses consisted of only social sciences students while the teams in iPjBL consisted of students from social sciences as well as natural and formal sciences. The social sciences branch includes students from psychology, economics, business administration, pedagogics, law, linguistics, geography, and politics. The natural sciences branch includes students from physics, environmental studies, and mechanical engineering. The formal sciences branch includes students from informatics.

To assess whether this has an impact in students' interdisciplinary competence development, additional multilevel models were conducted. Each team in iPjBL was assigned to either the "low distance" or "high distance" condition. The first refers to an interdisciplinary team where all team members come from one disciplinary branch; for example, all students came from social sciences. The second refers to interdisciplinary teams where team members came from two of three disciplinary branches; for example, three students from social sciences and three students from natural sciences.

Table 4. Multilevel models regarding Interdisciplinary Skills, Reflective Behavior, Recognizing Disciplinary Perspectives in iPjBL with Low and High Distance of disciplines.

	Interdisciplinary Skills		**Reflective Behavior**		**Recognizing Disciplinary Perspectives**	
	B	95% CI [*LL*,*UL*]	*B*	95% CI [*LL*,*UL*]	*B*	95% CI [*LL*,*UL*]
Intercept [Low Distance]	3.58***	[3.38, 3.78]	3.53***	[3.34, 3.72]	3.54***	[3.16, 3.83]
High Distance	0.03	[–0.36, 0.41]	0.08	[–0.30, 0.42]	0.06	[–0.24, 0.38]
R^2		–.11		.63		.55

Note. CI = confidence interval; *LL* = lower limit; *UL* = upper limit. $N_{low\ Distance} = 20$, $N_{high\ Distance} = 17$.
R^2 was computed following Hox (2002).
***$p < .001$.

The results indicate no difference in interdisciplinary teams in iPjBL with high or low distance of disciplines regarding the development of interdisciplinary skills, reflective behavior, and recognizing disciplinary perspectives (see Table 4).

Discussion

As the theoretical considerations suggest, iPBL is found to achieve better results than iPjBL when it comes to interdisciplinary competence. The development of interdisciplinary skills, reflective behavior, and the recognition of disciplinary perspectives is higher in iPBL than in iPjBL. These results are in line with the four instructional principles proposed by the pragmatic-constructionist theory on interdisciplinary learning, which states that one can facilitate interdisciplinary integration in an interdisciplinary learning environment by letting students establish their own interdisciplinary purpose, helping them gain disciplinary insights, and facilitating interdisciplinary synthesis and reflection. These aspects are facilitated by the specific steps in iPBL. The results also support designing learning environments with constructive alignment. In iPBL, intended learning outcomes, teaching methods, and assessments are highly aligned. iPBL students are guided toward considering, connecting, and applying different disciplinary views in solving interdisciplinary problems (interdisciplinary skills), rethinking chosen problem solving strategies (reflective behavior), and considering discipline-based concepts, methods, and limitations (recognizing disciplinary perspectives). The iPBL teacher or tutor is process oriented and functions as a facilitator by asking directive questions toward interdisciplinary reflection and integration. The assessment is aligned with the learning process, since students follow the same steps as in their learning sessions. The results also support the recommendations by researchers on interdisciplinary teaching and learning to choose a design where students encounter questions, reflection, and gradual advancement (Manathunga et al., 2006; Spelt, Biemans, et al., 2009; Woods, 2007).

Descriptive data show that there is no change in iPjBL students' interdisciplinary skills, reflective behaviors, and recognition of disciplinary perspectives. These results are unexpected, since our theoretical considerations predicted low but positive effects. They are also not in line with recent findings (Fortuin & Bush, 2010; Solomon & Salfi, 2011). General steps of project management in iPjBL include some sort of interdisciplinary goal setting and a formulation of milestones with regard to interdisciplinary collaboration. These should enhance interdisciplinary understanding and integration as proposed by the pragmatic-constructionist theory on interdisciplinary learning. Furthermore, the principle of constructive alignment is followed in the iPjBL design with regard to aligning the focus of assessment and process on the interdisciplinary product. This is consistent with the intended learning outcome of the development of interdisciplinary competence, since part of it is defined as the ability to solve interdisciplinary problems.

One explanation could be the disciplinary diversity of iPjBL teams. In contrast to iPBL student teams that were all composed of team members from only one disciplinary branch, social sciences, iPjBL student teams had two types of composition: (1) rather low distance of disciplines by a composition of only students from social science, and (2) team compositions of students coming from two different branches (e.g., natural sciences and social sciences). Hence, they experience a higher distance of disciplines. Due to this higher distance of discipline-based information, data, methods, and theories between natural and social sciences, one could expect that interdisciplinary integration is even harder, and therefore, interdisciplinary competence might be harder to develop. So far, one study found the degree of diversity in interdisciplinary teams hindering interdisciplinary teamwork (Lovelace, Shapiro, & Weingart, 2001). However, the results in this study indicate no difference of interdisciplinary student teams in iPjBL with high and low distance in regard to interdisciplinary competence development.

Since PjBL is rather practically oriented, students might have experienced difficulties that are well known in practical interdisciplinary teams. Interdisciplinary teamwork has a large potential for conflicts, and most collaborations fail in practice (Kezar, 2005). Interdisciplinary teams experience difficulties in communication, disagreements on common goals, inappropriate expectations, and underestimation of the additional time and effort in interdisciplinary, collaborative work (Epstein, 2005; Repko, 2008). This explanation is supported by the high dropout rate of iPjBL students who quit their participation in the course. In accordance with this interpretation, iPBL teachers attributed the early termination to conflicts within the interdisciplinary teams. Recent research in integrative learning indicates that interdisciplinary learning in general is more prone to failure than conventional teaching methods (Lee, 2014). Consequently, interdisciplinary learning requires direct, explicit instruction (Lee, 2014; Spelt, Luning, van Boekel, & Mulder, 2015), especially for novices in interdisciplinarity (Clark, Kirschner, & Sweller, 2012) and inexperienced students in self-directed learning (Schmidt, Henny, & de Vries, 1992). With reference to PBL and PjBL, Barron et al. (1998) advocate to begin with PBL and then move on to PjBL later, taking into account students' learning processes. This could also apply to iPBL and iPjBL in that students might need stronger support and guidance in the interdisciplinary learning process at first with iPBL, and further along, with a certain

development in interdisciplinary competence, thrive for practical application in iPjBL. Another practical implication could be to include steps of iPBL into iPjBL. For example, one could instruct students to clarify concepts and terms of each discipline involved before starting the collaborative work on task analysis. Again, ideas could be collected in a multidisciplinary way and then structured by contrasting discrepancies, interrelationships, and gaps across disciplines as in iPBL, followed by an identification of integration opportunities. In the identifying solution phase of iPjBL, students could research topics related to their project not only in their discipline, but also read academic papers in others discipline with regard to gaining deeper insight into an unfamiliar discipline. Moreover, in the implementation phase of iPjBL, students could be instructed to switch roles across disciplines in task completion. Furthermore, the final assessment could include a reflection of the interdisciplinary team process to the final product.

There are several limitations in this study. Most importantly, successful interdisciplinary teaching and learning might depend on components other than the educational model, constituting a missing variable bias. Possible important variables could be personal characteristics of students like openness, diligence, curiosity, and patience (Spelt, Biemans, et al., 2009). Moreover, teachers' characteristics and attitudes (Hattie, 2008), as well as experience and expertise in interdisciplinary education, could have an impact in student learning and may have distorted the results (Spelt, Biemans, et al., 2009). In addition, the use of a self-report inventory for collecting data on competence may cast doubt on the validity of the measure. Clearly, self-reports lack objectivity since they are potentially biased and do not allow any inferences related to hard criteria the way standardized objective tests do. Nevertheless, research yielded promising results indicating relations of self-reports to grades and vocational success (Braun & Mishra, 2016; Braun, Sheikh, & Hannover, 2011; Wilson, Lizzio, & Ramsden, 1997). Addressing possible limitations to construct validity, Lattuca et al. (2013) indicate that the interdisciplinary competence scale might not fully describe the construct since their research is based on literature on interdisciplinarity that was more speculative than empirical. Consequently, the measurement of interdisciplinary competence could be insufficient in this study, since there is no agreed-upon definition of interdisciplinary competence in the scientific community. Some define interdisciplinary competence as interdisciplinary communication competence (Shen et al., 2015), interdisciplinary cultural competence (Pecukonis et al., 2008), or interdisciplinary collaboration competence (Brandstädter & Sonntag, 2016). Unfortunately, the definition of interdisciplinary competence applied in this study is the only one for which measuring instruments are available.

Future research could investigate relationships between student and teacher characteristics, as well as interactions with different teaching methods and intended learning outcomes. These include students' perceptions of coherence of intended learning outcomes, learning activities, and assessments, as well as subjective challenges of interdisciplinarity. To enhance the understanding of processes in iPjBL, longitudinal studies on team development and potential conflict have the potential to yield interesting and robust results. Moreover, qualitative interviews could shed light on students' experiences and the challenges of interdisciplinary teamwork.

Conclusion

In summary, we find that iPBL is far more suited than iPjBL to support students' development of interdisciplinary competence. Since this is the first empirical study on interdisciplinary competence development, this research heavily contributes to the understanding of interdisciplinary teaching and learning. By comparing core elements of (i)PBL and (i)PjBL and conducting a pre-post study design, this research strongly promotes the advantages of design-based research in higher education. In light of the urgent reforms regarding twenty-first century skill education, our findings indicate that redesigning curricula toward interdisciplinary learning, especially implementing iPBL, enhances interdisciplinary competence.

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