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Supporting integrative interdisciplinary research discourse: A case study analysis

Abstract

Interdisciplinary research varies in its integrativity – the degree to which the different disciplines are integrated. Addressing the question of how to create a more integrative interdisciplinary research discourse (IIRD), we propose a model based on Learning by Design, taking a design based research approach, to conceptualize its dynamics. Based on our model, a case study of interdisciplinary research in the fields of psychology, education and image information mining in remote sensing is discussed; finding that IIRD parts from a joint language and discourse, to include joint design/redesign, and grows to include a joint analysis. This research results in a better understanding of interdisciplinarity. In terms of research practices, it suggests how practical interdisciplinary research scenarios can be more effectively structured.

1 Introduction

Interdisciplinary research comes with its own challenges. To begin with, it is not always easy for researchers to step outside their discipline and initiate collaboration with researchers from different disciplines (who will often even sit in different offices in different locations). Even after collaboration is established, the researcher must face the challenge of acquiring additional content and methodological knowledge from the different disciplines involved (Golde & Gallagher, 1999). This can be especially difficult when treading on new interdisciplinary ground, which has no accepted "state of the art" to build on. Additionally, there is often concern that there will not be sufficient publication outlets for interdisciplinary research, or that such journals will not be widely recognized by the home discipline (Golde & Gallagher, 1999). This is also related to the fact that there may not be a historical traditional for interdisciplinary studies (Morse, Nielsen-Pincus, Force & Wulfhorst, 2007).

Despite its challenges, interdisciplinary research is associated with positive outcomes. When researchers part from an interdisciplinary approach, they look at research questions in new ways (Bruhn, 2000), therefore not only fostering novel, creative answers to existing questions, but also prompting new questions (Lattuca, 2003). Interest in it has been increasing, evidenced in the creation of

study programs such as neuroscience (Golde & Gallagher, 1999), interdisciplinary traineeships (Morse et al., 2007), and its status as a criterion for public research funding (Carayol & Thi, 2005). Furthermore, outside the academic world, problem statements often require an interdisciplinary approach, therefore increasing demand for people with such a background (Golde & Gallagher, 1999). Despite all the positive aspects associated with interdisciplinary research; it has also been noted that not enough interdisciplinary research is being conducted (Morse et al., 2007).

This raises the question, what stimulates interdisciplinary research? Carayol and Thi (2005) grapple with this question. The authors create two measures: the degree of multidisciplinarity (measured at the level of a research lab, this measure considers the diversity in the disciplines of permanent researchers in the lab), and the degree of interdisciplinarity (measured at the individual level it considers the diversity in a given researcher's publications across scientific domains). Taking longitudinal data of more than 900 scientists from a large French university, the authors find that, among other results, a research setting (e.g. a lab) with a higher degree of multidisciplinarity is an important factor related to the interdisciplinarity of researchers' work.

While research has dealt with promoting interdisciplinary research, a topic that has not been sufficiently addressed is: how to create more *integrative* interdisciplinary research discourse (IIRD)? We consider this question in the context of existing interdisciplinary research, and explore the dynamics behind research with a higher degree of disciplinary integration.

In order to answer this question, we first consider the challenges that can be associated with conducting interdisciplinary research, namely that researchers may need to acquire additional content and methodological knowledge from different disciplines, and integrate it in a cohesive manner, often working without much prior research to build upon (Golde & Gallagher, 1999). This is a hurdle to make predictions, hypotheses, and plan the full scope of a research project. These challenges are likely even more pronounced for IIRD; however, they can be handled with an understanding of the dynamics of interdisciplinary research, and a step by step approach research design, each step building upon the previous one.

In this paper, we tackle the question of how to create more *integrative* interdisciplinary research discourse in two steps. We first propose a model of IIRD based on learning by design (LBD) (Kolodner, Gray & Fasse, 2003; Kolodner et al., 2003), and with elements of design based research (DBR). We then present a case study, and by using the model, we show that IIRD starts with a joint language and discourse, leading up to a joint design/redesign; growing to include joint analysis as it becomes more integrative.

2 Integrative interdisciplinary research discourse

This paper parts from the definition that interdisciplinarity is "*an adjective describing the interaction among two or more different disciplines. This interaction may range from simple communication of ideas to the mutual integration of organizing concepts, methodology, procedures, epistemology, terminology, data, and organization of research and education in a fairly large field. An interdisciplinary group consists of persons trained in different fields of knowledge (disciplines) with different concepts, methods, and data and terms organized into a common effort on a common problem with continuous intercommunication among the participants from the different disciplines*." (OECD 1972, pp. 25-26, in Lattuca, 2003).

As pointed out by Lattuca (2003) this definition implies that interdisciplinarity is not a binary concept, but rather exists on a spectrum. Within interdisciplinary research, we consider that there is a spectrum of "integrativity", referring to the degree to which the different disciplines are integrated in the research. We locate multidisciplinarity toward the end of low integrativity. In multidisciplinary research, there is a common problem, and researchers from separate disciplines bring their own tools and points of view to explore it. Interdisciplinary research, on the other hand, is said to occur when researchers from different disciplines bring their own knowledge to the table, and together decide on a problem to address, and how to address it (Golde & Gallagher, 1999).

This means that researchers from different disciplines will participate in a joint design of the research project, and to do so will share a joint language. Therefore, IIRD will part from a joint language, which will allow for a joint discourse, and move onto a joint design. The joint design, however, must be accommodating of the challenges presented by interdisciplinary research. An iterative, step by step approach provides the flexibility to continually build upon results, which is especially useful when there is not enough existing research to build upon. Our model, which depicts the dynamics of IIRD, is based on LBD (Kolodner, Gray & Fasse, 2003; Kolodner et al., 2003), which provides the theoretical grounding for our model. We also include elements of DBR, to further explain the iterations of design/redesign.

3 Learning by design

Lewin's (1952) model of action research and laboratory training was one of the first proposals where experience plays an important role in the learning cycle. This cycle has four stages, starting with concrete experience, which then leads to observations and reflections, which become the basis for forming theories, which are then tested with concrete experience (Lewin, 1952; Kolb, 1984). In

other words, after an experience, the learner will reflect and analyze what has occurred. This analysis is then synthesized, and transformed into an abstract concept that can be generalized.

Within the tradition of learning through experience is case based reasoning (CBR) (Kolodner, 1992). CBR starts when a problem is presented, and it is solved by referring to similar past experiences, either using past solutions as a guide and adapting them; or using them to justify proposed solutions (Kolodner, 1992). After the solution is selected and enacted, it must be critiqued and evaluated, then adapted again iteratively, till it is deemed appropriate. It should then be stored in memory, to serve as a past experience for future problem solving activities (Kolodner, 1992).

Although there are some drawbacks with CBR (e.g.: being biased by certain experiences); there are also several advantages, such as being able to find solutions to problems, even without complete understanding of the domains involved (perhaps because it is not our research domain, or the phenomenon itself is not well understood). Using CBR, it is possible to suggest a solution to a problem based on experiences with similar situations, even if all the mechanisms at hand are not understood (Kolodner, 1992). This is particularly useful in interdisciplinary research, where several researchers from different domains are collaborating.

Combining characteristics of CBR, such as its iterative approach and focus on the reinterpretation of experiences and the problem-based learning approach (which encourages group discussions to share existing knowledge drawing from past experiences, to propose hypotheses, with constant reflection and abstraction of lessons learned throughout, as well as tracking what knowledge is missing, and then evaluating the solution that was reached), LBD was born (Kolodner et al., 2003).

LBD emphasizes learning by experience to produce transferable knowledge (Kolodner, Gray et al., 2003). LBD is a cyclical model, with a design/redesign cycle, and an investigation/exploration cycle, which are brought together as the learner evaluates what is known, what knowledge is missing (this leads from the design/redesign cycle into the investigate/explore cycle), and what needs to be done to gather this knowledge (leading from the design/redesign to the investigate/explore cycle) (Kolodner, Gray et al., 2003). Working through these cycles iteratively results in a better solution to the problem (Kolodner, Gray et al., 2003). These two cycles are each composed of steps that are largely influenced by problem based learning, such as understanding the challenge or clarifying the question through "whiteboarding" (Kolodner et al., 2003). In terms of this paper, however, we will not discuss these smaller steps, but rather remain at the level of interconnected design/redesign and investigate/explore cycles.

LBD fosters collaboration in students by having them each become "experts" in different areas, and therefore they become dependent on each other to be able to solve the task (Kolodner et al., 2003). This mimics the situation in interdisciplinary research. Additionally, LBD is aligned with DBR, sharing iterative cycles of design/redesign. The next section presents an overview of DBR, with a focus on how it fits into our model of IIDR.

4 Design-Based research

DBR has been defined as "a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories" (Wang & Hannafin, 2005, pp. 6–7). While being pragmatic and ensuring research results are transferable to practice (which is facilitated considering the research context), DBR is also grounded, ensuring it is theory driven. DBR is integrative in its inclusion of different methods, which are constantly being re-evaluated with every iteration. Throughout this process, designers and participants work together, making it interactive (Wang & Hannafin, 2005). DBR recognizes that in complex environments (e.g.: educational settings), not all variables can be strictly controlled (Brown, 1992). DBR's flexibility, due in part to its iterative design, gives it the ability to adapt the study design to the context. As the properties of the context and the participants become clear, changes can be made in the design for the next iteration (Design-Based Research Collective, 2003).

DBR often makes use of mixed methods, gathering data from different sources, and triangulating data, which can present the challenge of gathering and analyzing a large amount of data (Design-Based Research Collective, 2003). However, data from multiple sources, alongside an iterative design, increase the reliability of findings, as well as validity (Design-Based Research Collective, 2003). Another challenge faced by DBR, is the generalizability of findings, since the design and redesign of studies are tailored to a specific context. This challenge can be overcome by the iterative analysis and triangulation of data, with a view to connect outcomes to their underlying processes (Design-Based Research Collective, 2003).

In DBR, data analysis is an important process of dialogue and consensus building (Design-Based Research Collective, 2003). This process, which requires a joint discourse, is an exercise in joint analysis, which is already taking a step toward a more IIRD. The results achieved through this process are not only focused on refining practice (a focus on outcomes), but strives to understand the processes and interactions involved in the outcomes (Design-Based Research

Collective, 2003). Thus, DBR not only refines practice, but also contributes to existing theory (Wang & Hannafin, 2005). The focus is often on results that will work outside the lab, that were reached through this iterative process and dialogue with experts in different areas (Cohen, Manion & Morrison, 2011).

In short, DBR can be characterized as pragmatic, grounded, interactive, iterative, integrative, and contextual (Wang & Hannafin, 2005). Its iterative design makes it compatible with LBD. In our model of IIRD, DBR is considered particularly important within the design/redesign cycle, where methods such as gathering data from many sources, the triangulation of data, and seeking ways to connect outcomes to process (Design-Based Research Collective, 2003) will strengthen the design.

5 A model of IIRD

Returning to our research question on how to create IIRD, we hypothesize that it parts from a joint language, joint discourse and joint design, and evolves to include a joint analysis. We present a model to depict this (Fig. 1) and in the following section we analyze a case study of interdisciplinary research based on this model.

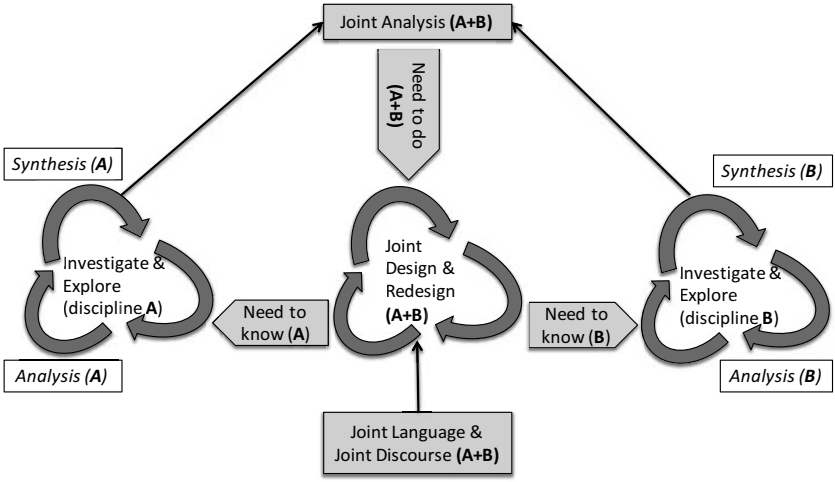

Figure 1: A model of IIRD, based on a LBD model (Kolodner, Gray et al., 2003), and DBR (Design-Based Research Collective, 2003)

Our model is based on LBD (Kolodner, Gray et al., 2003), which is particularly adept to IIRD because it assumes "experts" in different areas exist, and collaboration is therefore required to ensure design and learning objectives are met (Kolodner et al., 2003). This mimics the situation in an interdisciplinary research setting. LBD provides the theoretical grounding for our model. For the methodological grounding, we have identified DBR, with its iterative design that builds upon itself, as an appropriate methodology, particularly for the cycles of design/redesign. This iterative design is consistent with LBD (Kolodner, Gray et al., 2003).

The process depicted in the model starts with the establishment of a joint language and discourse, leading up to a joint problem definition which launches into a joint design phase. Following this, researchers from different disciplines will realize what knowledge they are still missing (what they "need to know") and they will move on to their independent cycles of investigation and exploration, where two important processes will occur: the analysis and the synthesis of data, similar to that which occurs in action research (Lewin, 1952). After having independently analyzed the data collected, researchers will embark in a joint analysis phase, where they will analyze the data in terms of results and their implications, as well as what new questions have been raised from the data. This leads researchers into another cycle design/redesign, to prepare for their second iteration of studies.

6 A case study of interdisciplinary research

The case study considered here is a research project that combines psychology, empirical pedagogy and image information mining in a remote sensing context, entitled "Acceptance of technology based conceptual artefacts in knowledge communities: Applications to Earth Observation (EO) Image Information Mining." The project involves four main researchers (including both authors), one from remote sensing and three from psychology and education (the last two disciplines are considered together for simplicity since they are conceptually closer to each other, than either is to remote sensing). The data was gathered by the authors over a period of one year and nine months, in the form of interviews and meeting notes, which were then analyzed to determine the processes involved in conducting the research. This case study presents a case where the model's principles are at play, and exemplifies how it is relevant for cases of IIRD.

The first step in undertaking the research project required dealing with the challenges of interdisciplinary research: gaining additional content and methodological knowledge of the different disciplines. We found that not all researchers had to acquire the same amount of knowledge in the different disciplines. While a

general understanding was necessary, only one researcher had to be more deeply submerged in the different disciplines. We will refer to this researcher as the "research coordinator", who had a good understanding of all disciplines and the project overview. Having someone in this role, who is also aware of the practical limitations of the project, is necessary to coordinate meetings, and the input which leads up to the research design. This also facilitates dialogue from a practical point of view. Not all researchers can be present at every meeting; therefore several meetings may take place around the same topic but viewed from different disciplinary perspectives. The research coordinator can guide the meetings, and note which information has to be passed on, issues that still need to be dealt with, and integrate the input given by all sides. The second step was to understand the research setting, including familiarization with the EO context, the knowledge communities involved, and the technological and conceptual artifacts. As these first two steps took place, the researchers developed a common vocabulary. This is indicative of the disciplines being bridged, and this culminated in the identification of research questions.

Working in an interdisciplinary research project often means treading new ground and will lack research to build on. This required that the larger scope of the research be broken down into smaller parts, taking on a step-wise approach so that research results build upon themselves. An iterative design served this purpose well, because it provides the flexibility to consider issues faced during the study, achieve results and evaluate their meaning, and consequently make adjustments to the study design for a subsequent phase of research.

An example of iterative design from the case study had to do with knowledge communities. The researchers conducted a pilot study to explore how the results of a human annotation of a satellite image (with a technological tool) could be used in an image information mining context (e.g.: as a reference data set). Additionally, the researchers had the general hypothesis that sense of community would have an effect on annotation task continuance and technology acceptance. A group of participants were recruited to conduct an image annotation task. They were told they were part of a group of volunteer annotators, and their results would be used to help advance semi-automatic computer algorithms for image annotation. After this task, participants were informally asked to answer questions regarding sense of community. The results showed that this task and study set-up was not enough to stimulate a sense of community. The researchers then moved to a redesign phase. It was considered that "precursors" of sense of community could be explored with their relationship to task continuance and acceptance. The study was tweaked, so that half the participants were told that their annotation work would be used for humanitarian task purposes, and the other half were told that their results would be used to improve algorithms. The annotation task was designed so that the image is annotated by two people, one participant started the task and created a semantic tree with the terms used, and

the second participant continued the annotation, based on the same semantic tree, with the possibility to add missing terms. This study produced interesting results, such as the relationship between social presence and task continuance and acceptance (these results are currently being prepared as a journal article). Based on these results, the researchers will design a study to continue exploring this topic. With an iterative approach, the technological aspects of the study, such as working with the technological tools, are intertwined with the socio-cognitive aspects, such as the corresponding conceptual artifacts and the community that uses them.

As described above, taking on an iterative approach, researchers jointly designed a first iteration, establishing goals and expected results, study procedure, methods, variables measured, sample, etc. This joint design phase concludes with researchers having determined what knowledge they are missing to answer their research questions, and the procedure by which to gather this data from within their own area of expertise. The experimental tasks are then carried out according to expertise. This means that portions of the study are carried out from the perspective of one discipline (mostly by researchers with an expertise in that discipline). Other portions of the study will be carried out from the perspective of the second discipline, largely by researchers with an expertise in that discipline. In the case study, for example, there was an initial goal of studying sense of community and its effects on task continuance for an image annotation task. A sub-goal within this was to identify conceptual artifacts, and explore the human interpretation of images from a sensory and semantic perspective. From the psychology and education perspective, it was important that participants be placed in different conditions (humanitarian or for the improvement of algorithms), either begin or end the annotation, and that questionnaires be answered. The annotations and semantic trees were the conceptual artifacts in this study. The researchers with expertise in these disciplines worked on this part of the experimental set-up. Once data was collected, it is analyzed in a preliminary manner, and results synthesized, to be shared with the research team.

From the image information mining/remote sensing perspective, the conceptual artifacts are used to study the difference between computer and human interpretations of an image from sensory and semantic perspectives. Researchers with an expertise in this carried out this portion of the study, and also conducted a preliminary analysis of the results, and then synthesized the data, so that results can be shared with the rest of the research team.

These processes culminated in a joint analysis of all the findings, by all the researchers. This step is important because the results and their implications are contextualized in terms of both disciplines. This joint analysis is also what then permits a joint discussion of results and brings together both disciplines in reaching conclusions and implications for both domains. It is at this point

that researchers re-consider their findings in terms of the research questions, and note new questions that are raised as a consequence of the findings, asking what research needs to be done to answer these new questions. Researchers will then place their results as the foundation for the second iteration of research.

7 Conclusions

The research question posed was how to create more IIRD, which we answer by first proposing a model, based on LDB (Kolodner, Gray, et al., 2003; Kolodner et al., 2003), and integrating elements of DBR (Design-Based Research Collective, 2003), to understand the dynamics of IIRD. We find that interdisciplinary research requires a *joint language*, a *joint discourse*, and a *joint design*. However, moving toward a more IIRD will require tackling the challenges of interdisciplinary research with an iterative, DBR approach. It will also require a *joint analysis* phase. It is in this phase that the different disciplines really come together, as the results and their implications are contextualized in terms of both disciplines. A joint analysis will also aid researchers in framing their results as the foundation for the second iteration of research, and determining what new questions have arisen, which could be addressed in a second iteration.

Based on our case study, we find that our model provides a helpful way of understanding the dynamics of IIRD. Our model incorporates the elements discussed above (joint language, discourse and design), which lead up to a joint *design/redesign* cycle, as researchers design studies to answer their jointly posed research questions. Our model also takes a DBR approach, because of its iterative nature (compatible with LBD; Kolodner, Gray, et al., 2003), together with its contextual, grounded, and interactive approach (Wang & Hannafin, 2005). Secondly, because DBR places emphasis in the data analysis phase, which is an exercise in consensus building through dialogue (Design-Based Research Collective, 2003). Additionally, DBR provides a methodological understanding for the design/redesign phases. After a phase of joint design, researchers will have the structure of their study, and will know what they *need to know* in terms of data to answer their research questions. At this point, researchers will begin *investigating and exploring* in their area of expertise: carrying out the research, and gathering data. There is one cycle of *investigate/explore* for each discipline, because gathering data and exploring is likely done on a disciplinary basis. Once data has been gathered within each discipline, it will be *analyzed and synthesized*, so that it can be presented to the rest of the research team. All researchers then embark on a *joint analysis* of all the results, contextualizing them within each discipline, and determining their implications as groundwork for posing new questions to be tackled in the second iteration of research. At this point

researchers determine what they *need to do* to be able to tackle these new questions, which leads them directly back to the cycle of *design and redesign*.

Future research can first focus on identifying strategies or techniques for existing multidisciplinary or interdisciplinary research which is seeking to be more integrative. Future research can also address additional questions, such as: will even more integrative interdisciplinary research evolve to include a phase of joint synthesis? Does this depend on the common ground shared by the disciplines in question? Perhaps interdisciplinary research between education and psychology could be integrated to the degree that there is one cycle of design/redesign and one cycle of investigation/exploration. On the other hand, this might not be possible to achieve for disciplines that have very little overlap in theory and methods, such as psychology and informatics, for example. As more interdisciplinary research is carried out, of all degrees of integrativity, it is necessary to understand its dynamics, and consider its implications for existing models related to conceptual artefact development, such as communities of practice, and knowledge communities.

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