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A suggested framework and guidelines for learning GIS in interdisciplinary research

Patrick Rickles, Claire Ellul and Muki Haklay

Interdisciplinary research with geographic information systems (GIS) can be rewarding as researchers from different disciplines have the opportunity to create something novel. GIS, though, is known to be difficult to use and learn. It is imperative for its successful use in projects that those who need to use GIS are able to learn it quickly and easily. To better support interdisciplinary research with GIS, it is necessary to understand what researchers with interdisciplinary experience wanted to use it for and how they learned it. The aim would be to advise geography educators on creating learning resources that could compliment or supplement existing learning approaches used by interdisciplinary researchers to improve the learning experience and uptake of GIS. This article explores the results from an online survey and interviews conducted between July 2014 and August 2015 with participants from the UK, the US and Europe on how interdisciplinary researchers learned GIS and which resources and platforms were utilised. Guidelines and a framework are presented, modifying the Technological Pedagogical and Content Knowledge framework, incorporating informal and context-based learning and GIS concepts from the Geographic Information Science and Technology Body of Knowledge. Findings show that interdisciplinary researchers want to use GIS to capture, analyse and visualise information; they largely use informal learning approaches (e.g. internet searches, watching a video, ask a more experienced person); and they predominantly use ArcGIS, QGIS and web GIS platforms. Future work suggests resources use contextually relevant learning activities and bear in mind nuances of disciplinary language.

Key words geographic information systems; interdisciplinary research; Geographic Information Science and Technology Body of Knowledge; informal learning; context-based learning; Technological Pedagogical and Content Knowledge framework

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Introduction

Disciplinary ways of thinking are instilled in students by faculty as part of formal education (Chick *et al*. 2009), so different disciplines approach problems in different ways. It is even possible to discern differences in how arguments are generated, developed, expressed, and reported in different disciplines (Becher and Trowler 2001). This highlights how language and literature play a key role in establishing a discipline's identity, excluding those who have not been 'initiated' into it (Becher and Trowler 2001). Becher and Trowler (2001) have identified disciplines as being convergent and divergent; the former are representative of disciplines that will defend their established norms and resist or reject those who attempt to question them, and the latter of disciplines that lack a clear sense of mutual cohesion and identity. In particular, geography is said to be an example of a loosely knit, divergent disciplinary group, as:

> Its practitioners readily absorb ideas and techniques from neighbouring intellectual territories, and even identify themselves with other academic professions than their own (through publications in their journals, attendance at their conferences and membership of their communication networks). (Becher and Trowler 2001, 59).

Collaboration between geography and other disciplines occurs frequently, as geography lends its tools and methodologies to other subjects and can integrate them from outside (Clawson and Johnson 2004). Geographic information systems (GIS), one of geography's tools for locational analyses, may not only be considered useful by other disciplines, but has also been said to be a fundamental tool for research (Chen 1998). To begin to understand GIS, researchers must learn key disciplinary concepts of geographic information science (GIScience), which is needed to understand the internal language of GIS (Kuhn 2012). Kuhn (2012) therefore suggests the need for geographic knowledge and GIS concepts to connect spatial data and analyses to domain problems across disciplines.

Interdisciplinary research brings together people from two or more disciplines to work in such a collaborative fashion across disciplinary boundaries; this approach to research facilitates the combination of different methodologies from the disciplines in order to try to answer multifaceted, real world problems (Aboelela *et al*. 2007). GIS has been used and applied in many highly cited interdisciplinary studies on topics such as the use of corn for biofuel (Sheehan *et al*. 2003, cited over 550 times as of July 2017), predicting and monitoring landslide hazards (Carrara *et al*. 1999, cited over 350 times as of July 2017), and mapping disease outbreaks (Nuckols *et al*. 2004, cited over 300 times as of July 2017). These ideas are further explored in the section 'GIS in interdisciplinary research'.

Such interdisciplinary research projects can be rewarding for researchers, though learning and applying GIS can be challenging. Central to this is the complexity of the GIS itself, which through its 40 years of development has led to confusing, poorly defined functionality and a lack of any conceptual framework or organisational structure (Goodchild 2011). Indeed, learning how to use GIS can be difficult for a variety of reasons, which may include hardware and software issues as well as lack of training (Liu *et al*. 2012). However, even with GIS training opportunities, learners may consider the concepts or materials dull and not engage with them, consider them hard to grasp and become afraid of the software (Hualong 2009), or have very low levels of knowledge retention if they have not at least previously 'played' with GIS in order to know what questions to ask (Middlestead no date). It is therefore imperative for GIS learning programmes or curricula to carefully consider the audience and tailor materials accordingly to create a conducive learning environment to improve uptake.

There is a growing and evolving international community concerned with GIS education that includes people in full-time education, consultancies, government, academia, educational associations, non-profit organisations and private companies (Kerski 2008). In particular, we are GIScience academics with experience in interdisciplinary research and have seen the difficulties colleagues from other disciplines have experienced when learning GIS. One of the aims of our research is, through investigating how interdisciplinary researchers have previously learned GIS, that we may identify which concepts are of interest to such researchers and that we may also be able to evaluate learning approaches; from this, we would seek to improve educational practices and associated materials for such future learners to better accommodate them. Given that we are interested in how the interdisciplinary researcher creates knowledge, our research is set within constructivism and will explore possible constructivist learning theories to use as a foundation for materials and activities, as well as to evaluate results and frame discussion. Another aim of our research is to propose and modify, if necessary, an education-based framework to act as the structure for which GIS concepts can focus on and how to convey the information to interdisciplinary researchers, using relevant mediums and GIS platforms.

The focus of this article is on how to improve learning GIS in an interdisciplinary research context. To explore this, we identify which GIS platforms are used by interdisciplinary researchers, what may be GIS concepts of importance, and learning approaches that may have been employed to learn GIS. We start with the existing literature on interdisciplinary research, GIS, and constructivist educational theories, identifying overlapping areas, and suggest a framework that addresses aspects relevant to learning GIS in an interdisciplinary setting. Next, we review the collected data from an online survey and interviews with those who had previously undertaken interdisciplinary work with GIS. These data were collected between July 2014 and August 2015 from adult learners who were university researchers primarily from the UK, the US and Europe. Due to low participation numbers, these results should be taken as preliminary and should be used to inform future work. Finally, we discuss associated findings to rationalise the proposed framework for best practice in teaching GIS, along with guidelines on how to improve future GIS learning experiences for interdisciplinary researchers.

Learning, interdisciplinarity and GIS

To understand the background of how to improve learning GIS in an interdisciplinary research context, it is first necessary to understand the nature of interdisciplinary research itself. The following section will investigate GIS applications in interdisciplinary research and examine conducive learning approaches. Existing GIS learning programmes and curricula are then reviewed to understand and frame concepts to identify which ones are relevant to interdisciplinary researchers. A combination of the previous concepts then address the difference between formal and informal GIS learning approaches when interdisciplinary researchers learn GIS. A review of existing educational

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frameworks has identified one that may provide a foundation to link the diverse concepts described.

Defining interdisciplinary research

When addressing research problems, researchers will approach them from the background of their discipline: '… a branch of learning or scholarly instruction which is defined by institutional boundaries constructed by the needs of teaching, funding, administration, and professional development' (Bracken 2017, 1). Yet, as Barry and Born (2013, 9) noted, 'Disciplinary boundaries are neither entirely fixed nor fluid; rather, they are relational and in formation'. The fluidity may create overlapping research areas that may encourage researchers to collaborate with others from different disciplines with common goals; however, there are differences between types of collaboration that may be of interest. Based on levels of interaction, these types may be defined as multidisciplinary, interdisciplinary and transdisciplinary. Multidisciplinary approaches are ones that involve several disciplines that each provide a different perspective on a problem or issue (Stember 1991). Researchers on multidisciplinary projects will work in a 'parallel play' mode, completing work in their disciplinary work streams and exchanging outputs as and when needed, only fostering a loose continued connection between researchers (Aboelela *et al*. 2007). The term interdisciplinary research is sometimes used for multidisciplinary research; in a broad sense, '… interdisciplinarity literally means "between disciplines", suggesting the basic elements of at least two collaborators, at least two disciplines, and a commitment to work together in some fashion in some domain' (Stember 1991, 4). To clarify, though, interdisciplinary research may be considered that in which the contributions of several disciplines are integrated and, more importantly, necessary to address a problem or issue (Stember 1991). The data and analytical methods may also be more mixed, requiring researchers from one discipline to learn, at least a bit, about methodologies from the other disciplines (Aboelela *et al*. 2007). Transdisciplinary work, in comparison, involves the unity of intellectual frameworks beyond the disciplinary perspectives (Stember 1991) and may lead to the establishment of a new discipline altogether. Problems are stated in a way that includes completely new language; new analytical methods are established that will be a synthesis of work from the disciplines and outputs from the project are completely new (Aboelela *et al*. 2007).

Here, we focus on interdisciplinary research, rather than multidisciplinary or transdisciplinary, as prominent organisations believe that many future discoveries will come from this specific type of research (National Academy of Sciences *et al*. 2004). Barry and Born (2013) also recognise this, stating that interdisciplinarity is seen as '… a necessary response to intensifying demands that research should become more integrated than before with society and the economy …' and '… has come to be at once a governmental demand, a reflexive orientation within the academy, and an object of knowledge' (pp. 4–5). The participants in the online survey and interviews (see below), probably used the broader understanding of interdisciplinary, perhaps overlapping with multidisciplinary, to define themselves as having relevant experience; however, they still saw the use of GIS with their disciplinary methodologies as a novelty, which may be considered as interdisciplinary.

GIS in interdisciplinary research

Geography is well placed to undertake interdisciplinary research and a wealth of successful interdisciplinary research projects involving geographers already exists (Bracken 2017). This may be because geography itself is interdisciplinary in nature, as its different approaches to social science and physical science map onto very different ways of working (Bracken 2017). This diversity within the discipline of geography itself may be considered its strength, as Sheppard and Plummer (2007) emphasise that this acts as a foundation of intellectual interaction that advances the subject and geographical knowledge. To apply geographic knowledge to contexts in different disciplines, though, it is still necessary to develop a level of understanding of its standards for production and development (Firth 2011). The epistemological basis of geographic research has indeed changed over time to be more inclusive of practices from other disciplines (Staeheli and Mitchell 2005; Ward 2005). This has helped foster better methods of thinking geographically and how to research geographic questions across the discipline – from human to physical geography (Hubbard *et al*. 2005). Through understanding disciplinary practices that govern the creation, validation, representation, interpretation and critique of geographical knowledge, it may then be applied to specific domains and different disciplines, developing a learner's disposition towards the knowledge (Firth 2011). This puts geography at a nexus where it can act as an integratory discipline that facilitates interdisciplinary research. Data, as a basic element to begin any analysis, often have spatial components that need consideration – everything happens somewhere and geography is the stage on which all natural and human activity occurs (Lawrence 2009).

The locational element is one of the most powerful parts of geographic analyses, which can be done using GIS. GIS is a useful tool to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information (Esri 1990). GIS can be a supportive tool for interdisciplinary research by being able to integrate a variety of different data sources (Albrecht 1998), consequently supporting

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researchers across disciplines. The use of GIS through interdisciplinary approaches provides opportunities to contribute to major challenges of humanity; Kuhn (2012) identifies that spatial information at global, regional and local scales is essential for addressing issues such as biodiversity, climate change, cultural heritage, debt, energy, water, natural hazards, health, poverty or security.

Such interdisciplinary applications of GIS can also help to expand understanding of what is possible with this tool and inspire others to think of new ways to use it. Interdisciplinary studies with GIS, because of their novel approaches, have the potential to be highly recognised; for example, as identified by Rickles and Ellul (2014b), 'Interactions between groundwater and surface water: the state of the science' (Sophocleous 2002) was one of the most prominent studies using GIS as part of interdisciplinary research. This has been highly cited (over 1200 times as of July 2017) and there are good reasons to believe that the methodologies within it had an impact on practice. Given the growing interest in using GIS, there is a need for new users to properly understand GIS concepts. Rickles and Ellul (2014a) suggested providing training on disciplinary tools and methodologies to help create common understanding for those coming from outside of the discipline who may not be familiar with such concepts.

Learning for interdisciplinary research: a review of problem-based and context-based learning

Of interest to the research here, for learning GIS concepts, is problem-based learning (PBL) and context-based learning (CBL). Both PBL and CBL may be said to have their foundations in constructivism, which views learning as an active process of constructing rather than acquiring knowledge and that instruction is a process of supporting that construction rather than communicating knowledge (Cunningham and Duffy 1996). This epistemological framework is also conducive for interdisciplinary research, as knowledge is created through the interplay between people and tools and their disciplinary knowledge (Rickles and Ellul 2014a). PBL:

> … suggests that for effective acquisition of knowledge, learners need to be stimulated to restructure information they already know within a realistic context, to gain new knowledge, and to then elaborate on the new information they have learned. (Kilroy 2004, 411)

This approach has already been identified by a variety of studies as being effective for learning GIS (Bednarz 2000; Kerski 2003; Hualong 2009; Liu *et al*. 2010; Rickles and Ellul 2014a). PBL is said to be a subset of CBL (Overton *et al*. 2009); therefore, CBL may also be a viable approach for learning GIS. CBL is described as:

> … a pedagogical methodology that, in all its disparate forms, centers on the belief that both the social context of the learning environment and the real, concrete context of knowing are pivotal in the acquisition and processing of knowledge. (Rose 2012, 799)

A key distinction of CBL is the recognised dual axis of context – one focusing on the social situation of learning ('learning environment context') and the other on the knowledge interface of the learning activity with actual, empirical reality ('learning activity context') (Rose 2012). Both the 'learning environment context' and the 'learning activity context' are part of the proposed framework that we present later. Further learning approaches are outside the scope of this paper, and will not be covered here.

With respect to PBL, it has been said that the authenticity (i.e. relevance to real-world problems) of the designed PBL activities is key to engaging the interdisciplinary learner and allowing them to reflect on the learning process when learning GIS (Rickles and Ellul 2014a). Kerski (2003) notes that teaching GIS provides the opportunity for an inquiry-oriented or inquiry-based learning approach, which includes PBL (Prince and Felder 2006). The effectiveness of this approach, though, is somewhat limited by social and structural barriers (Kerski 2003). Indeed, it is recognised that PBL can be difficult with GIS (Kerski 2003) and, more generally, is time consuming (Kerski 2003; Kilroy 2004). As time constraints are already a recognised challenge that affects interdisciplinary researchers (Rickles and Ellul 2014a), PBL may not be feasible to implement.

In planning learning activities, CBL allows the creation of materials in advance, whereas PBL largely assumes the learner and educator form these together. This practice is time and labour intensive for both learners and educators, which may make CBL easier to implement. However, this does not require prescription of the entire learning interaction; the balance of lesson preparation and exploration of topics of interest to the students is key to adult education, known as andragogy. Andragogy acknowledges that adults learn differently to children, and additionally, learning is problem centred with learners having interest in immediate application of knowledge (Merriam 2004). Within pedagogy, the art and science of teaching children (Knowles 1973), it is recognised by Vygotsky (1962) that children need to build spontaneous, experiential concepts through structures created by scientific, learned knowledge to make consciousness and deliberate use of them. Indeed, adults have accumulated life experiences and so have an independent self-concept and may direct their learning. Self-directed learning also occurs as part of adults' everyday lives and is systematic yet does not depend on an instructor or a classroom (Tough 1971). This also fits the definition of informal learning, which is not typically class based or

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highly structured, and control of learning rests with the learner (Marsick and Watkins 1990); therefore, it may be said that adults regularly use informal learning approaches.

Informal learning and CBL, though both are complimentary to andragogy, are very different methods of learning. With CBL, educators use constructed materials to impart disciplinary knowledge to learners; while in informal learning, learners must seek out information themselves. To do so, they may talk to people or search for information online; this may make learning difficult if the learner does not use the correct terminology when asking questions. Therefore, learners will need to learn basic terminology around the topic they are studying in order to ask the right questions.

GIS learning programmes and curricula

In formal GIS learning programmes, standardisation efforts attempt to set what GIS concepts one should learn for professional certification. One of the most prominent textbooks used to teach these topics is *Geographical information systems and science* (Longley *et al*. 2005), which has sold over 100,000 copies internationally and is available in English, Polish, Korean, Chinese, Portuguese and Greek (Longley, personal communication, 01 November 2016). The contents outlined in this book, which includes information on geographic data collection, analysis and decision-making, reflects introductory material relating to topics that may be used as part of formal learning programmes geographic information scientists (GIScientists) receive. Some efforts for standardised curricula include the Geographer's Craft Project (Foote 2001 2012), the European GIS Curriculum (Kemp and Frank 1996), the Revision of Berry's Geographic Matrix for GIS (Sui 1995), and the Japanese Standard GIS Core Curriculum (Sasaki *et al*. 2008; Kawabata *et al*. 2010). One of the first prominent ones, though, was the National Center for Geographic Information and Analysis (NCGIA) Core Curriculum, which was highly successful and delivered to 736 interested institutions globally (Goodchild and Kemp 1992). The Geographic Information Science & Technology (GIS&T) Body of Knowledge (BoK) is a more contemporary effort that has gained traction, having built upon the NCGIA Core Curriculum and is recognised as its successor (DiBiase *et al*. 2007). The work in this article, therefore, uses the GIS&T BoK to frame GIS concepts, which are summarised as 10 knowledge areas (KAs) in Table 1.

The KAs are broken down into 73 units and 329 topics for interchangeable use and focus on concepts of interest. The GIS&T BoK provides guidance on concepts but, as critiqued, focuses on '… content mastery rather than who (the learner), what (the intended outcome) and how (the designed teaching and learning process)' (Prager 2011, 67). Foote *et al*. (2012, 8) also point out 'although the BoK suggests developing "multiple pathways to diverse outcomes," none were developed for the first edition'. To address

Table 1 GIS&T BoK – KAs and descriptions

GIS&T BoK KA	*Description*
Analytical Methods	Topics encompassing a wide variety of operations whose objective is to derive analytical results from geospatial data
Cartography and Visualisation	Topics primarily related to the visual display of geographic information
Conceptual Foundations	Topics that recognise, identify, and appreciate the explicit spatial, spatio-temporal, and semantic components of the geographic environment at an ontological and epistemological level in preparation for modelling the environment with geographic data and analysis
Data Manipulation	Topics on manipulations of spatial and spatio-temporal data such as (1) their transformation into formats that facilitate subsequent analysis, (2) generalisation and aggregation that affect the accuracy and integrity of the data used for analysis, and (3) transaction management that allows for the tracking of changes, versioning, and updating without loss of the original data
Data Modelling	Topics that deal with representation of formalised spatial and spatio-temporal reality through data models and the translation of these data models into data structures that are capable of being implemented within a computational environment (i.e. within a GIS)
Design Aspects	Topics on proper design of geospatial applications, models, and databases and the validation and verification of design activities
Geocomputation	Topics that emphasise the research, development, and application of computationally intensive approaches to the study of complex spatial-temporal problems
Geospatial Data	Topics on measurements of the locations and attributes of phenomena at or near Earth's surface
GIS&T and Society	Topics that encompass critical approaches that question the assumptions and premises that underlie the economic, legal, and political regimes and institutional structures within which GIS&T is implemented
Organisational and Institutional Aspects	Topics which consider the management of GIS hardware, software, data, and workforce within and among private and public organisations

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its shortcomings, the GIS&T BoK is being revised (GIS&T BoK 2: Re-engineering the GIS&T Body of Knowledge 2014); however, this was not yet available at the time of the subsequent work, so the original GIS&T BoK was used.

A framework for learning GIS in interdisciplinary research

Though the GIS&T BoK provides a formal educational structure for those from GIScience to learn GIS, it may not be possible to apply it in the same way for interdisciplinary researchers. This may be because of the way they learn GIS or because the concepts they attempt to learn are not adequately covered in an understandable way. As identified by Baker *et al.* (2012), the implications of GIS learning and measurement of GIS knowledge and application continue to be research gaps in the area of GIS education. Furthermore, studies about how different disciplines have used GIS and which concepts mattered to them are lacking. Without such information, GIScience is missing an opportunity to grow.

To identify the theoretical elements of GIS concepts and educational approaches from previous sections within a single framework, we use the Technological Pedagogical Content Knowledge (TPACK) framework (Figure 1). The initial concept of this framework was formed by Pedagogical Knowledge and Content Knowledge (Shulman 1987) and later amended by Mishra and Koehler (2006) to add Technological Knowledge. This framework recognises not only the importance of each of these elements, but their overlaps as well; each part and their intersections is described in Koehler (no date) as follows:

- Pedagogical Knowledge (PK): teachers' deep knowledge about the processes and practices or methods of teaching and learning (Learning Approaches).
- Content Knowledge (CK): teachers' knowledge about the subject matter to learn or teach (Subject Area Expertise).
- Technological Knowledge (TK): knowledge about certain ways of thinking about, and working with technology, tools and resources (Understanding and Application of Technology).
- Pedagogical Content Knowledge (PCK): the teaching of specific content (Teaching Subject Area Expertise through Learning Approaches).
- Technological Pedagogical Knowledge (TPK): an understanding of how teaching and learning can change when particular technologies are used in particular ways (Learning Approaches for Understanding and Application of Technology).
- Technological Content Knowledge (TCK): an understanding of the manner in which technology and content influence and constrain one another (Teaching Subject Area Expertise through Understanding and Application of Technology).
- Technological Pedagogical Content Knowledge (TPACK): the basis of effective teaching with technology, requiring an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face; knowledge of students' prior knowledge and theories of epistemology; and knowledge of how technologies can be used to build on existing knowledge to develop new epistemologies or strengthen old ones (Teaching Subject Area Expertise and use of Learning Approaches for Understanding and Application of Technology).
- Context: described as the unique situational factors associated with, but not limited to, individual teachers, grade level, school specific factors and demographics (Institutional Learning Environment).

Using Figure 1 as the basis, Figure 2 maps the main tenants of this research to the TPACK framework and is summarised as follows:

- Pedagogical Knowledge (PK): CBL.
- Content Knowledge (CK): GIS&T BoK.
- Technological Knowledge (TK): Use of GIS.
- Pedagogical Content Knowledge (PCK): Learning GIS&T BoK through CBL.
- Technological Pedagogical Knowledge (TPK): CBL for Use of GIS.
- Technological Content Knowledge (TCK): Teaching GIS&T BoK for Use of GIS.
- Technological Pedagogical Content Knowledge (TPACK): Teaching and Learning GIS&T BoK through CBL for Use of GIS.
- Context: Institutional Learning Environment.

Using the TPACK framework to summarise the mapped elements of this work suggests Teaching and Learning necessary GIS&T BoK concepts through CBL for the Use of GIS, supported by the Context of the Institutional Learning Environment. To explore this conclusion from the reviewed literature, it is necessary to gather further supporting evidence. Which GIS platforms have interdisciplinary researchers used to do the work they needed to do (Technological Knowledge)? CBL is the suggested learning approach (Pedagogical Knowledge); however, which approaches do interdisciplinary researchers use? Framed by the GIS&T BoK (Content Knowledge), with which GIS concepts are interdisciplinary researchers actively engaging?

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Figure 1 Technological Pedagogical Content Knowledge (TPACK) framework

Documenting existing learning experiences

Therefore, to fill the gaps identified an online survey and a series of interviews were carried out, focusing on the following questions:

1. Which GIS platforms have participants used?
2. How did participants obtain information on GIS concepts?
3. Which GIS concepts were important to the participants?

Identified GIS platforms for the survey included first ArcGIS (2016) (including desktop, server and online versions) and QGIS (2016), the top two platforms used in the GIS industry (Mapping Out the GIS Software Landscape 2016). Google Earth (2016), Google Maps (2016), MapInfo (2016) and Manifold (2016) were also included as these are also commonly used platforms (Hinks 2013; Best GIS Software 2016). For the interviews, respondents were initially asked about the same GIS platforms listed in the survey, but others were included in the outputs if mentioned by interviewees. Similarly, for how information was gathered, commonly used methods were suggested (e.g. internet search, ask a more experienced person, etc.) and incorporated into the survey. The interviews asked about the same methods, but other resources were included that participants discussed. Finally, for simplicity, GIS concepts inquired about were at the GIS&T BoK KA level, rather than unit or topic level. Participants were asked in the survey and interviews about the KAs, by being presented a descriptive statement of them or a few of their topics, with further information made available upon request. It should be noted for both the surveys and interviews that though the authors attempted to recruit as many participants as possible from a variety of disciplines, they had trouble reaching wider audiences than anticipated. This is a recognised barrier in interdisciplinary research, as

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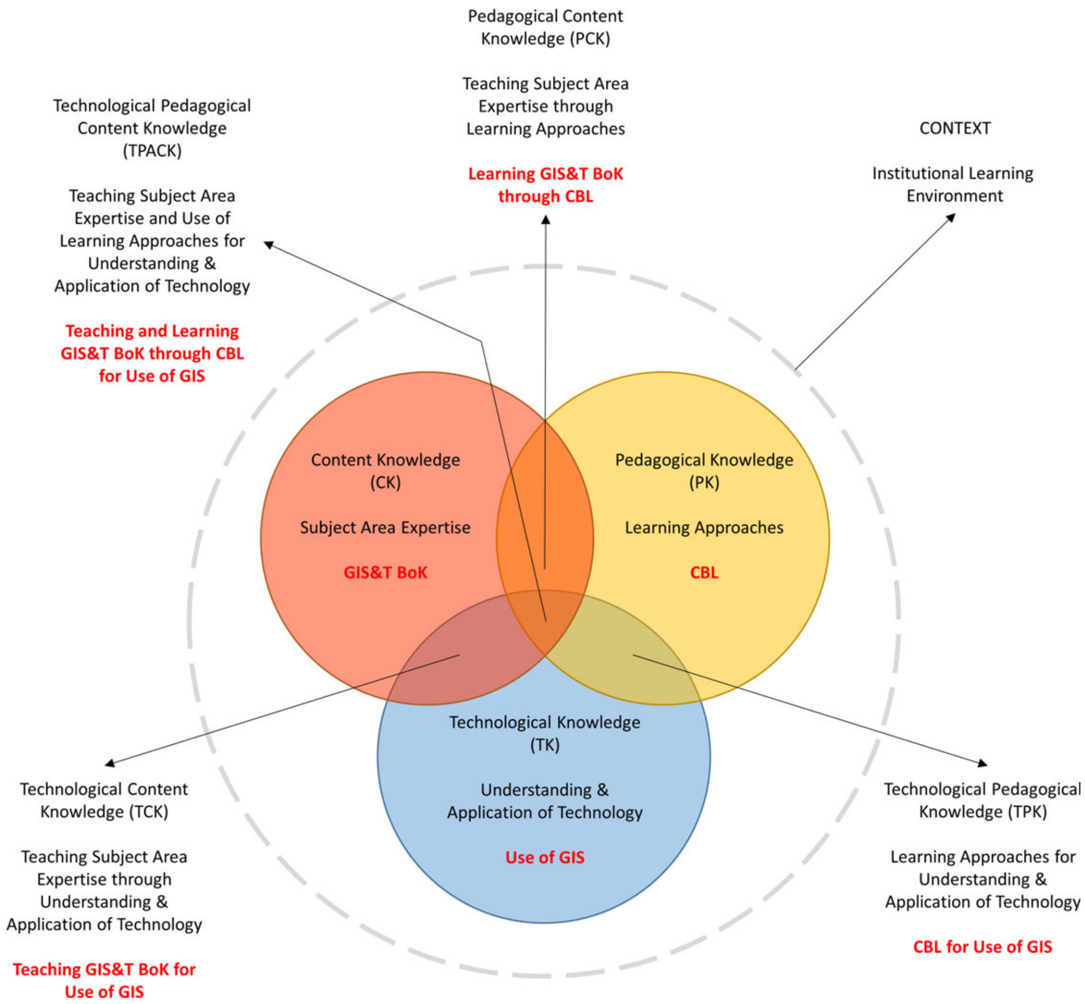

Figure 2 TPACK framework with research elements mapped to it

identifying participants outside of one's network to establish communications and contacts is problematic (Augsburg and Henry 2009).

Online survey

Methodology The online survey, which was conducted between August 2014 and 2015 via advertising through email, Twitter and at geography and GIScience conferences, collected information about those who have been involved in interdisciplinary research and how they learned GIS for their work. Questions were associated with which GIS platforms participants used and their level of experience with them, whether it was none, some, moderate or (almost) daily experience. The survey asked respondents about methods of obtaining information on GIS, which included an internet search, watching a video, following a tutorial, using a software help manual, asking a more experienced person, or posting on a forum. Efficacy of the methods was also explored. With respect to GIS concepts, the survey asked respondents about the relevance of certain phrases that mapped to GIS&T BoK KAs (from extremely relevant to not relevant) to the work they had done with GIS (outlined in Table 2). A final, open-ended question was asked in which respondents could contribute any further information.

Analysis Review of the responses was done by tabulating and reclassifying information, as necessary. Although we planned, in the case of sufficient number of responses, to carry out a quantitative analysis of survey results, eventually we had 45 responses and therefore a more qualitative approach would be taken. This approach was used to identify patterns in the data through reviewing charts and statistics from the data and comparing those with information respondents gave in the final, open-ended question. Any responses

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Table 2 Descriptions used to represent GIS&T BoK KAs utilised as part of the online survey

GIS&T BoK KA	*Survey description*
Analytical Methods	I have queried and analysed geospatial data in a GIS
Cartography and Visualisation	I have designed and created maps in a GIS
Conceptual Foundations	I have questioned the spatial relationships or philosophical perspectives of GIS data
Data Manipulation	I have used a GIS to prepare maps at different scales or convert map data from one format to another
Data Modelling	I have structured and managed data in a GIS database
Design Aspects	I have planned the system design and deployment of a GIS
Geocomputation	I have created algorithms or modelling processes which take into account uncertainty inside a GIS
Geospatial Data	I have created new data inside of a GIS and/or used satellite imagery inside of a GIS
GIS&T and Society	I have had to be concerned about the legal aspects or ethics of the data in a GIS
Organisational and Institutional Aspects	I have formatted GIS data in a way that improves its usability by others

to the open-ended question that might provide new avenues of inquiry were also taken into consideration and shared.

Results Of the 45 responses gathered, respondents identified their disciplinary backgrounds from 17 unique disciplines, which included GIScience (6), geography (physical and human) (4), remote sensing (3), computer science and software engineering (2), forestry (2), cartography (1), ecology (1), education (1), general humanities (1), history (1), librarianship (1), marine biology (1), music (1), oceanography (1), petroleum engineering (1), psychology (1), and urban and rural planning (1) (16 respondents did not identify their discipline).

The results show that respondents were most experienced with ArcGIS, Google Earth and Google Maps; less so with QGIS and MapInfo; only four respondents had experience with Manifold; and only three respondents had used gvSIG (2016) (Figure 3). Other GIS platforms that were named in an open text 'Other' field that was provided were GeoMedia (2016) (2 respondents), GRASS GIS (2016), Neatline (2016), MapWindow GIS (2016), Terra Amazon (2016), ERDAS IMAGINE (2016), PostGIS (2016), CartoDB (2016) (now CARTO), GeoServer (2016), and MiraMon Map Reader (2016). These were not included as part of Figure 3 as they were not identified by a significant number of respondents (less than 5%).

Figure 4 highlights that all respondents felt an internet search was effective and many felt watching a video (89%), asking a more experienced person (87%) and following a tutorial (87%) were also effective; however, in comparison, only 48 per cent considered posting on a forum to be effective.

Figure 5 shows that respondents felt that almost all of the short descriptive statements, which represented the various KAs of the GIS&T BoK, reflected important GIS concepts. Many respondents felt that those representing Data Aspects, Geocomputation, and GIS&T and Society were not relevant (40%, 33% and 28%, respectively). It is worth noting that over 90 per cent of respondents felt that Analytical Methods, and Cartography and Visualisation were relevant.

In the final, open-ended question, of interest to this research, 15 respondents said that when they performed an internet search, they would mention the GIS platform and would include specialist terms (e.g. 'buffer', 'cluster', 'raster', etc.). One respondent also said that they believed many people could benefit from applying GIS to their analyses, but that they might not be aware of how it could positively contribute to them.

Interviews

Methodology To gain a more in-depth understanding than is possible in an online survey, individuals from various institutes were invited to participate in a series of semi-structured interviews, held between July 2014 and 2015. Individuals were contacted through professional networks and asked to share their experiences around learning to use GIS as part of interdisciplinary research. Interviewees were asked which GIS platforms they use, how they obtain information on GIS, and what terms they may use when searching for information. Afterwards, interviewees were asked to do an exercise of arranging cards with key phrases on them that represented selected topics from KAs in the GIS&T BoK, ranking them in respect to their importance to the researchers' work. Table 3 outlines the topics listed on the cards as descriptors of the GIS&T BoK KAs.

The descriptions used on the cards differed from those offered in the survey because the descriptions in the survey needed to be self-explanatory. Interviewees, though, would be able to request further details on the descriptions on the cards from the interviewer, should any of the topics not be understandable.

Analysis During the interviews, audio recordings of the interviews were made so they could be reviewed afterwards and any relevant points of interest would be transcribed. To record the results of the card arranging

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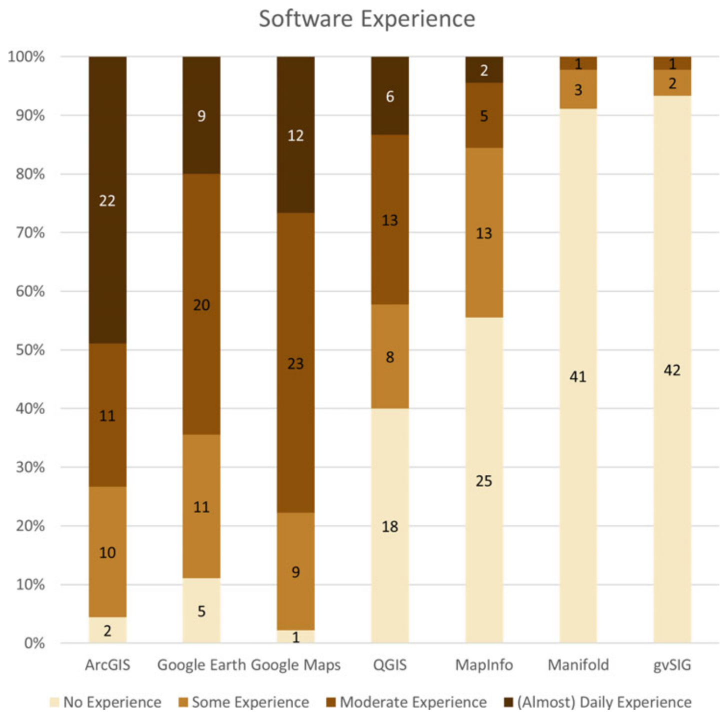

Figure 3 Online survey results – GIS platforms used (45 responses)

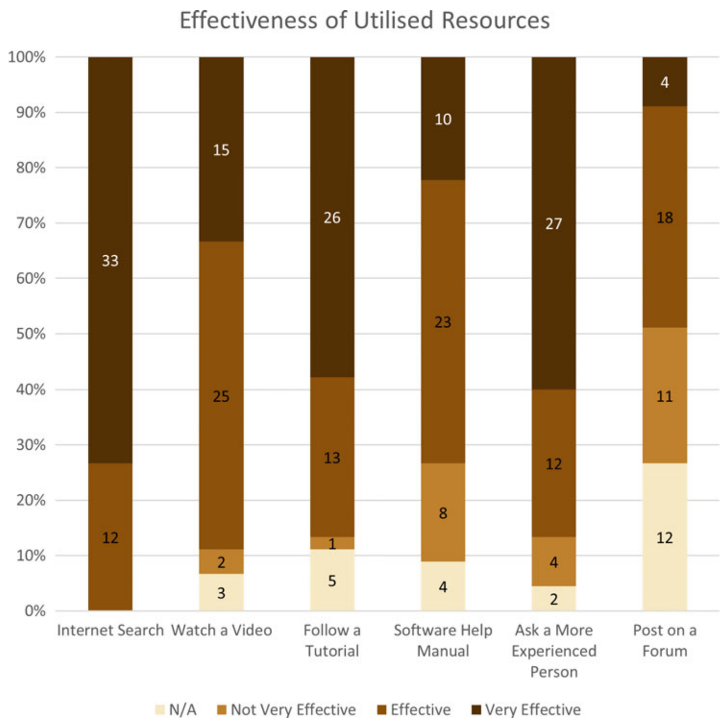

Figure 4 Online survey results – methods for obtaining information (45 responses)

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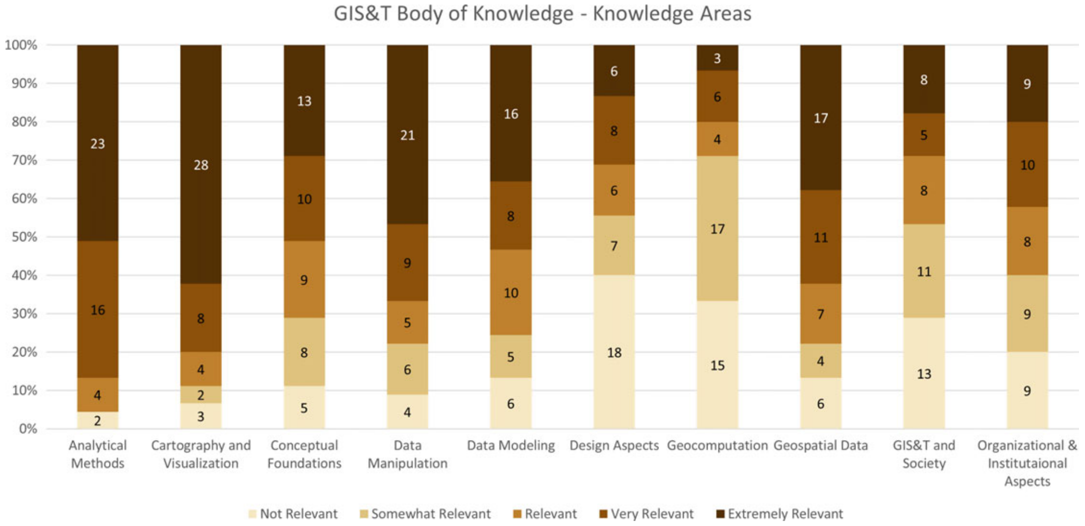

Figure 5 Online survey results – importance of GIS&T BoK KAs (45 responses)

Table 3 Card descriptions using topics from GIS&T BoK KAs utilised as part of the interview activity

GIS&T BoK KA	*Card description (topics)*
Analytical Methods	Attribute and spatial queries, geometric measures, spatial and network analyses
Cartography and Visualisation	Symbolisation, spatialisation, map design and production
Conceptual Foundations	Space and time, philosophical perspectives, spatial relationships
Data Manipulation	Generalisation, interpolation, transformations
Data Modelling	Database management, triangulated irregular networks (TINs), 3D models
Design Aspects	Resource planning, database design, user interfaces
Geocomputation	Genetic algorithms, simulation modelling, fuzzy sets
Geospatial Data	Georeferencing systems and map projections, digitising, GPS and satellite imagery
GIS&T and Society	Legal aspects, ethics, property rights
Organisational and Institutional Aspects	Systems management, staff development and training opportunities, spatial data infrastructures (SDIs) and standardisation

exercises, photos were taken. After the interviews, the interviewer made notes about any key points that may have emerged during the interview and transcribed the recordings.

Results In total, 11 interviews were conducted. These interviewees identified their disciplinary backgrounds as being from anthropology (2), archaeology (1), architecture (1), ecology (1), evolutionary biology (1), library sciences (1), marine biology (1), molecular biology (1), psychology (1), and sociology (1). In regards to GIS platforms, they predominantly used QGIS, ArcGIS, and web GIS platforms (Google Maps 2016; OpenStreetMap 2016; GPSies 2016; Sketchup 2016), and bespoke ones (such as Community Maps 2016; Wheelmap 2016; SeaSketch 2016), as seen in Figure 6; Manifold and MapInfo, on the other hand, exhibited very little in the way of use and other GIS technologies mentioned were R (2016) and the Global Positioning System (GPS). Three interviewees commented on using QGIS and web GIS platforms because they were considered simple and user friendly.

> It's a lot easier to start with something like, say, Google Maps, which has got really simple tools, because I did find the Manifold interface quite difficult. (Participant E)

> . . . I found it [QGIS] a lot easier to use because it was very basic, but also used ArcGIS with in depth, lengthy layer files as QGIS didn't have the necessary processing power. (Participant D)

> QGIS seems more user friendly; all the buttons seem to make sense. (Participant J)

Figure 7 shows that interviewees searching for answers mostly asked a more experienced person (91%), did an internet search (91%), or watched a video (73%). Other methods used include taking a short course (18%), reading a book (18%) or using social media (9%).

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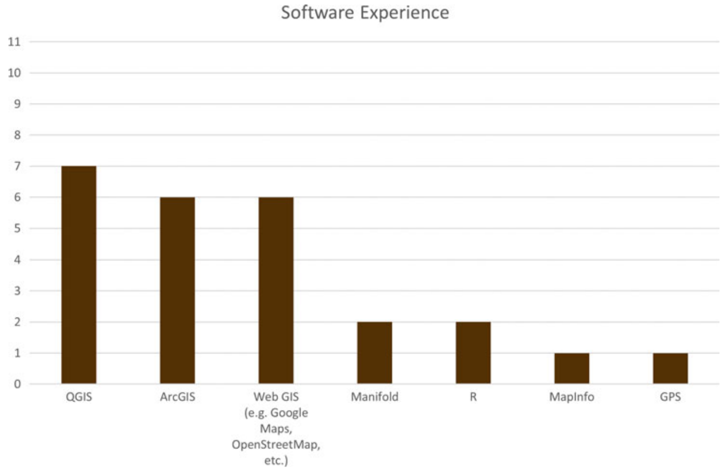

Figure 6 Interview results – GIS platforms used (11 interviews)

> You can just spend ages wandering around [in regards to internet searches for information] and not knowing what you're doing, and actually that can be very negative because then you can get frustrated and daunted and feel a bit of an idiot. Whereas if you just, say, ask somebody for help, then, you know, they can show you how to do something and it can be a much more positive experience. (Participant E)

> I used YouTube a lot . . . I kind of like this process of 'you click here', you can see where the arrow is going on the screen, you can see what that person is doing, you can see the outputs of that, and they're talking you through it. (Participant A)

> [For internet searches] Always put in the software; the answer will come back using the software that you use and it'll also be in layman's terms so that I understand it. (Participant D)

When asked about the GIS&T BoK KAs, interviewees felt Cartography and Visualisation was the most relevant, followed by Geospatial Data, and then Analytical Methods, as shown in Figure 8. Interestingly, not a single interviewee believed Cartography and Visualisation to be irrelevant: 'I think that [Cartography and Visualisation] is really important because that's the power of the map' (Participant E).

While interviewees shared their experiences, the semi-structured nature of the interviews allowed investigation of other topics. One that came up in every interview, especially during the exercise with the GIS&T BoK KAs cards, was the difficulty of understanding GIS or discipline-specific language. For example:

> . . . I find there's a lot of this in GIS language, there's a lot of bullshit, a lot of 'I can't be bothered to tell you what this language means'. (Participant A)

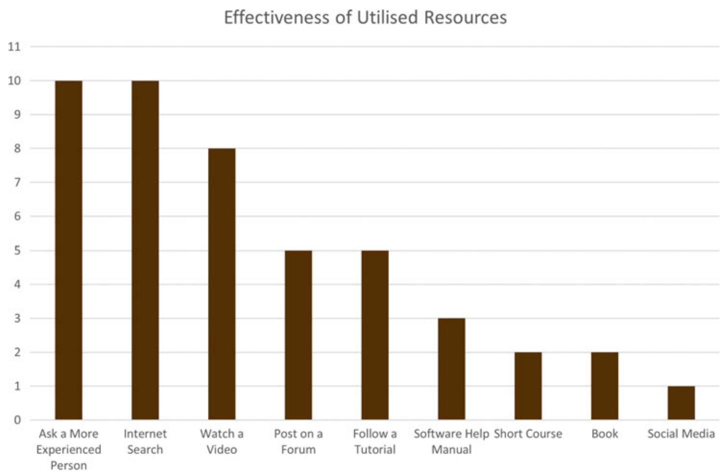

Figure 7 Interview results – methods for obtaining information (11 interviews)

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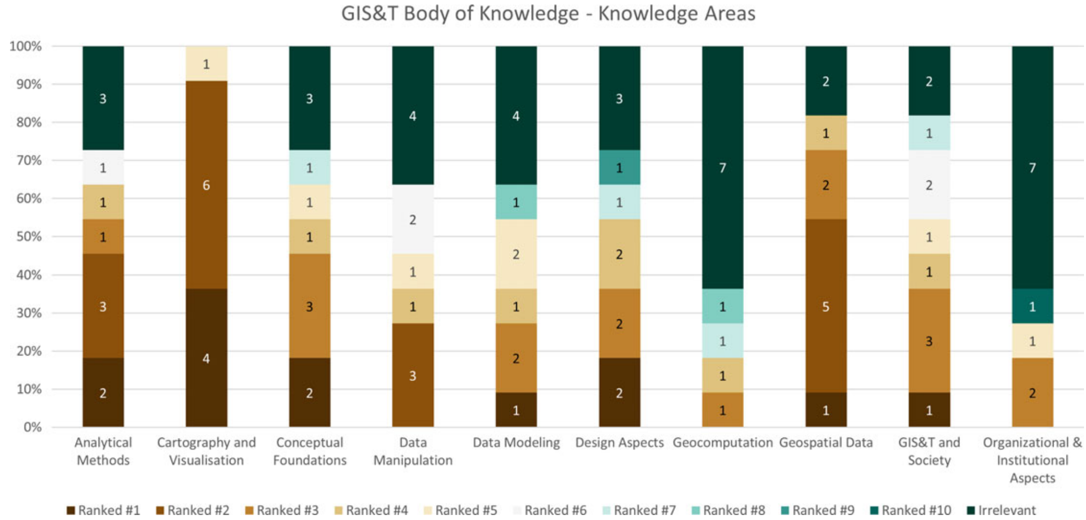

Figure 8 Interview results – importance of GIS&T BoK KAs (11 interviews)

> They [GIS&T BoK KAs] are all kind of jargon-y ... Just slapping 'Geo' at the beginning of something doesn't necessarily help anybody. (Participant I)

> I don't really understand a lot of them [words used] ... A lot of it's quite jargon-y. (Participant J)

Discussion: a framework for learning GIS in interdisciplinary research

We opened this paper by asking how to improve learning GIS in an interdisciplinary research context. While necessarily limited by the number of respondents to the online survey and participants in the interviews, these results provide a preliminary insight into efficiencies and hindrances in the process of interdisciplinary researchers learning GIS. Users tend to utilise informal learning approaches (e.g. internet searches, watching a video, or asking a more experienced person). However, as noted by one of the interviewees, without properly knowing what they want to do with a GIS, researchers may spend a large amount of time searching for information, not knowing if they have found the answer they needed, which can be frustrating.

If these learners were to find examples of what may be done with GIS within their discipline, as suggested by one of the online survey respondents, not only would they be able to understand what is possible with GIS, but they may also be in a better position to understand what they might want to achieve with it by seeing something familiar. By creating learning resources that can be more easily discovered online, via informal approaches that interdisciplinary researchers use and provide examples that are contextually relevant to learners' disciplines, including the steps on how they were created, it may be possible to reach new disciplinary audiences with GIS. Therefore, it may be suggested that informal learning approaches may be improved through the addition of CBL structures to create contextually relevant learning materials, which may be a more conducive approach for interdisciplinary researchers learning GIS.

Use of GIS platforms

These results show the preference for ArcGIS (desktop, server, online) and web GIS platforms, though QGIS was also prominently used. These platforms should be the focus of Technological Knowledge with respect to the TPACK framework when applied to interdisciplinary researchers learning GIS.

Reflecting on the interview results (Figure 6), QGIS may have been the more utilised platform due to growing culture of using open source tools that is becoming part of the core of academia's own culture (Wiley 2006). Nevertheless, this falls in line with expected results, as ArcGIS and QGIS are the top two platforms used in the GIS industry (Mapping Out the GIS Software Landscape 2016). The difficulty with the desktop-based platforms, though, is that they often require sufficient hardware to run them; however, most web GIS platforms may simply be accessed by any computer or mobile device with a network connection and internet browser. ArcGIS Online as a particular web GIS platform provides a unique benefit, as it builds on an industry-recognised software suite and achieves the benefits of being available online. This platform has been said to be transformative in higher education and that web GIS platforms in general '... continue to push

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the creativity of educators for new ways to teach GST [Geospatial Technologies]' (Perkins 2015, 81).

GIS curriculum in framing concepts relevant to interdisciplinary research

As discovered through previous work, Geospatial Data and Analytical Methods are prominent GIS&T BoK KAs (Rickles and Ellul 2014b); however, the interviews and online survey highlighted the importance of the Cartography and Visualisation KA, so future materials should include topics from that one as well. These GIS concepts may be considered to relate to the Content Knowledge of the TPACK framework and should be ones that learning resources prioritise if being constructed for interdisciplinary researchers.

Reflecting on the definition of a GIS, these concepts are core to it, in that a GIS is one that captures spatial information (Geospatial Data), analyses it (Analytical Methods), and displays it (Cartography and Visualisation). The application of the GIS&T BoK to frame concepts can expedite compilation of relevant materials for interdisciplinary researchers to help them quickly learn what they need. This will help with alleviating pressures on time and helping them avoid ineffectively searching for information on GIS tasks. Difficulties exist, however, with applying the GIS&T BoK due to its level of specificity and lack of clarity for modular pathways of application of concepts. This is especially challenging for researchers coming from disciplines outside of geography or GIScience, as their disciplines may approach issues in different ways, or they may not understand the internal language of GIS. Should an educator with expertise in GIS be available to personalise training using the GIS&T BoK as guidance, they would need to identify what the researcher needs to learn, map that to the GIS concepts and then deliver materials. Intricate knowledge of the GIS&T BoK may be required for determining appropriate application; the lack of guidance on modularly building a curriculum based around combined concepts and the time and resources required to compile learning materials may make this a difficult task to accomplish. Alternatively, one could receive a general overview of topics from within KAs identified as having relevant concepts to the learner's objectives. This, however, may also cover inessential topics that the learner may not want or need to learn; with 329 topics, the matter of whether they are indeed inessential may be worth exploring as part of future research.

Methods of learning GIS in interdisciplinary research

Figures 4 and 7 show that internet searches, watching a video or asking a more experienced person were the most popular methods for obtaining information. Following a tutorial and the software help manual, though, were methods some also employed for finding information; however, respondents to the survey, in comparison to the interviewees, viewed posting on a forum less favourably. These informal learning approaches and the proposed CBL structure for them compliment the Pedagogical Knowledge aspect of the TPACK framework and are methods that may benefit interdisciplinary researchers.

Online methods for finding information should highlight the importance of learning materials being available and accessible online as well as teaching basic terminology around the topic. Discipline-specific terms should also be simplified or explained with terms more frequently used in searches, to enable easier discovery and understanding of topics. Conflicting definitions or misunderstandings of disciplinary language may negatively affect interdisciplinary learners. As identified in the section 'Learning, interdisciplinarity and GIS', interdisciplinary research requires the establishment of a common language; however, vocabulary from different disciplines may conflict or cause confusion. Without knowing the correct terms, learners may end up searching in vain for answers and not find them. As described by one interviewee:

> The frustrating thing is that I think there's help out there for everything that you want to do, but even if you put in all the terms you can think of, it still might not come up, and it takes ages searching through things that are irrelevant, but you're not sure if the things you're looking at are relevant or not, because you're not sure what it is you're trying to do. Sometimes you spend an hour trawling through forums thinking 'I'm not sure if this is going to help me, or not'. (Participant J)

Therefore, if the learners do not know the right terms to find the information they may need and they cannot use ones they understand, regardless of whether it exists, a resource that may have the information they are looking for will not be of much help to them because it is unlikely they will find it.

As GIS use in interdisciplinary research continues to proliferate, GIS educators will need to create resources that help to overcome issues associated with terms and concepts, such as a dictionary of terms (Esri 2016; Wiki.GIS.com 2016; GISGeography 2016). Whether learners actively make use of these, though, is an open question. Instead, resources should provide built-in dictionaries to address vocabulary knowledge gaps, so learners do not need to go elsewhere for answers, or simply avoid terms that require defining, when possible.

Outside of issues with language, sharing contextually relevant examples of GIS use in various disciplines may let disciplinary researchers know what is possible with GIS and how it may be of use to them. Interweaving terms familiar to those outside disciplines as part of these examples and materials may enable them to be

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found more quickly, leading to expedited uptake of GIS. With focus on how the learner creates knowledge on GIS, constructivism as a framework can help to improve the learning process. CBL suggests that to aid in the development of knowledge, learning activities should be relevant to learners; with respect to GIS, this can help them focus on the GIS concepts they wish to learn, rather than unnecessary details. This is done by removing information identified as extraneous or not relevant to the learner, which may only distract or overwhelm learners. Further supporting CBL as a viable approach is its link to PBL, which has a variety of studies to recommend it for learning GIS (see the section 'Learning for interdisciplinary research'). CBL may even be preferable, given that it may be able to offset time constraints for the geography educator, as materials may be prepared in advance. Through the GIS educator's guidance, a CBL resource constructed in a more formalised way may benefit the learner and still compliment (or perhaps supplement) a more informal learning approach. This was not able to be explored in detail within this research; however, it is suggested for future work to do so, using the literature review and these preliminary outputs as a foundation.

Adapting the TPACK framework

With respect to the TPACK framework (Figure 2), the use of context is in reference to the institutional learning environment; as suggested by CBL, though, this should also include the context of the problem domain for the learning activity. These two contexts are the Learning Environment Context and the Learning Activity Context respectively, which relates back to the dual axis of context, as recognised by Rose (2012). The Learning Activity Context affects Content Knowledge, Pedagogical Knowledge, and Technological Knowledge, as it may necessitate changes to any of these elements; however, the Learning Environment Context exists at a higher level, which may affect all elements, including the Learning Activity Context.

Incorporating these updates, the modified TPACK framework for Learning GIS in Interdisciplinary Research in Figure 9 further builds on Figure 2 and maps to the various tenants and outputs of this research. At its nexus, it suggests Teaching and Learning necessary GIS&T BoK concepts [Analytical Methods (AM), Cartography and Visualisation (CV), and Geospatial Data (GD)] through CBL that compliments informal learning, using relevant Learning Activity Contexts for Use of GIS (e.g. ArcGIS, QGIS, web GIS platforms), supported by the Learning Environment Context.

This work can then set forth the following guidelines to help better support these researchers in learning GIS:

- Content Knowledge: from the GIS&T BoK, KAs Analytical Methods, Geospatial Data, and Cartography and Visualisation are of high importance for interdisciplinary learners and therefore, these should be the KAs focused on by learning resources.
- Pedagogical Knowledge: in practice, though survey respondents and interviewees used informal approaches, CBL approaches may be used to compliment or supplement these, which may better support interdisciplinary researchers learning GIS.
- Technological Knowledge: though survey respondents and interviewees used established GIS platforms (e.g. ArcGIS, QGIS), it is worth noting the prominence of web GIS technologies and their easy implementation and deployment in interdisciplinary research projects.

Conclusions and further work

The versatility of GIS and its potential for interdisciplinary research has led to its incorporation in many such projects; however, there is a learning curve in using GIS, which needs to be overcome. In order to provide those learning it effective resources, it is important to understand how other researchers have previously learned GIS. Though informal learning approaches (e.g. internet searches, watching a video, asking a more experienced person) were commonly utilised, materials using a constructivist approach, such as CBL, may better support the learner by providing them with information on relevant GIS concepts and act as a foundation for educators developing the materials. This will allow them to be created in advance, perhaps alleviating time pressures on geography educators, providing a flexible activity structure to act as a guide for topic exploration.

Application of the modified TPACK framework for learning GIS in interdisciplinary research and proposed guidelines may improve the learning experience for interdisciplinary researchers. It is suggested that CBL resources be created that compliment or supplement existing informal learning approaches, while being sensitive to the nuances of disciplinary language to minimise misunderstandings. In general, all the different participants in the GIS chain have a role to play in conveying information in an understandable way – from software vendors ensuring that their tools are usable and as jargon-free as possible, to educators by providing introductory courses not only on specialist programmes but as part of more general scientific training. If this is done in a contextually relevant way that feels familiar to learners from different disciplines, this may help them to focus on the GIS concepts they wish to learn rather than extraneous information.

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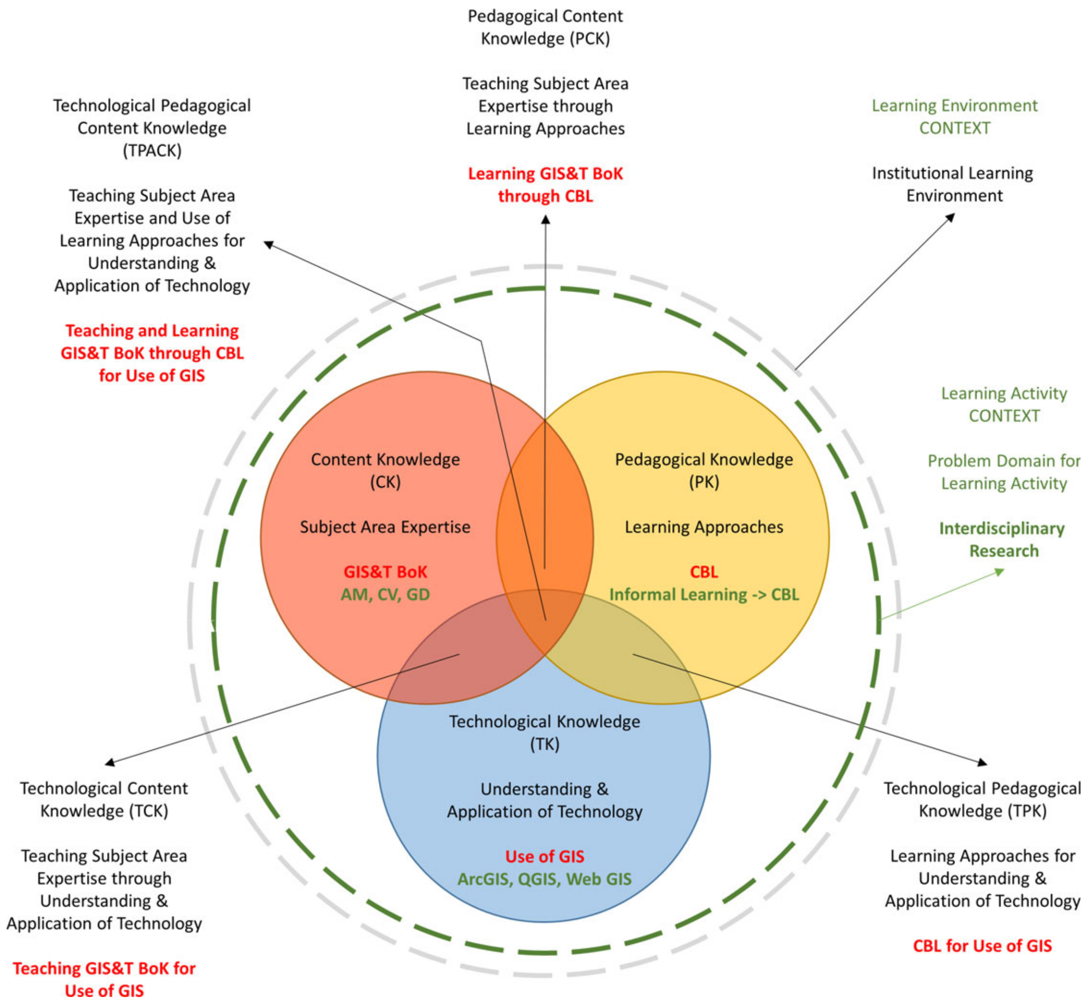

Figure 9 Modified TPACK framework for learning GIS in interdisciplinary research

It is hoped through future research that a CBL resource about GIS for interdisciplinary researchers may be created that would focus on capturing, analysing and visualising information, using the GIS platforms relevant to interdisciplinary researchers. This should be purposefully created by geography educators and then be trialled with researchers, ideally in active interdisciplinary projects, to gather data on learning GIS and compare to informal approaches. The proposed work may be able to provide further evidence on whether CBL is a more suitable learning approach than informal learning for interdisciplinary researchers learning GIS and applied to existing educational practices. Through handling the challenges associated with the knowledge gap on GIS, facilitating quicker and easier uptake, GIS educators may better support researchers in expediting the application of GIS on projects to achieve interdisciplinary research goals.

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