Learning design is not a prescription: Framing and disposition in collaborative infrastructure

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Same task, same instructions, same tools, different outcomes. What students bring to a group assessment task, their disposition, and how they make sense of what is being asked of them, their framing, will influence how they explicitly and tacitly construct and use a collaborative infrastructure. Learning design can nudge towards a particular path, but a project and its supporting infrastructure is ultimately the epistemic work of the student group. In findings from case studies of seven group projects at an Australian university I compare framing and disposition of the groups with the infrastructure that they created around assessment tasks. I place the cases under three loose categories of shared knowledge creation and proffer suggestions for learning design, including individually-produced artefacts as part of group knowledge creation.

Keywords: sociomaterial, collaboration, objects, infrastructure, framing, disposition, design

Introduction

There is a recognized need for graduates to be good collaborative problem solvers, but there has been a lack of research into related student practices (Graesser, Fiore, Greiff, Andrews-Todd, Foltz & Hesse, 2018). Infrastructure is not something to be instrumentally prescribed and designed for students, but constructed by learners. As students work on open-ended or complex problems, their knowledge work is embedded in the environment and objects they find and create: within a distributed cognitive (Hollan, Hutchins & Kirsh, 2000) infrastructure. Learning design should be about "supporting learners in organizing complexity and sense-making" as they engage with the many available resources and tools (Damșa, Nerland & Andreadakis, 2019, p. 3). To do this, we need to know more about students' infrastructure for shared knowledge creation, and what might support them in this process.

The aim of the main study from which the findings in this paper originate was to investigate how university students create knowledge together–what infrastructure they assembled and built, and how that infrastructure influenced their epistemic work. The seven case groups constructed unique infrastructures through activity in support of their projects and related epistemic work. Research questions for this paper are, for university student groups, 'What influences how infrastructure is assembled and used?' and 'What infrastructure do students assemble to support knowledge-based tasks?' I share a summary of part of the study findings, concentrating on group disposition towards and framing of assessment tasks and the shape of their collaborative infrastructure. 'Infrastructure,' in this context, is expansively defined to include tool use, processes, and found and created objects: what students do and use to complete their task. All cases are covered in brief, with more detail on two cases of individuals contributing substantial artefacts to group knowledge creation. Implications for learning design are outlined in the discussion.

Literature

In any task, but especially an open-ended or complex project, student groups need to assemble an infrastructure. Infrastructure is emergent from activity and assembled in use: students work out how to do things in practice, and accommodate to, or adapt, the tools at hand (Damșa et al., 2019). Each student brings their particular experiences, skills and expectations to a task—a particular disposition—and the group needs to make sense of their assessment task and how to approach it. In an open-ended project especially, the group is required to create knowledge together. Here I briefly outline relevant concepts in explaining how students came to create an infrastructure around shared knowledge creation: sociomaterial activity; framing; disposition; and infrastructure and its constituent parts.

I took a sociomaterial view of activity in this study, in attending to how students created knowledge together, what they did and said, what tools they used and the objects they assembled and created (Johri, 2011). The knowledge creation metaphor "is a kind of individual and collective learning that goes beyond information given and advances knowledge and understanding: there is collaborative, systematic development of common objects of activity" (Paavola & Hakkarainen, 2005, p. 536). 'Common objects of activity' means both artefacts and concepts: anything that can be developed and shared by a group. Students are thinking with and through objects: what they create, their material and conceptual infrastructure, is key to building situated knowledge. Situated, because knowledge is created uniquely in application to a particular problem. The type of knowledge and how it is created depends on how group members exercise agency—recognise and act on opportunity. They need to frame the task appropriately.

Framing here is how a group makes sense of an assessment task and understands what their response to it should be, in effect their answer to "What is going on here?" (Goffman, 1974, p. 8). Students frame a task at both a high level, around the project as a whole and how it aligns with longer-term goals, and the local level of immediate action, such as the topic of a particular conversation or what to post online (Goffman, 1974; Scherr & Hammer, 2009). Framing describes how students approach a task epistemically, that is, how they understand what type of knowledge, related conceptual work and practical steps are required. It is not necessarily explicit or stated but evidenced in the activities of students.

Why do different groups frame the same task differently? An expanded view of dispositions offers a conceptual approach to how students understand and react to an assessment task, often in quite different ways. Perkins, Jay & Tishman (1993) define disposition as a composite, combining the three elements of sensitivity to occasion, inclination, and abilities. This is expressed mnemonically as the 'detect-elect-connect' model (Perkins & Salomon, 2012). A sensitivity to occasion is to detect that a situation requires a particular response, and this may arise from, for example, experiencing similar situations, or from environmental or designed cues. Inclination is volition, electing to act in a certain way: one may have formed a habit, value particular opportunities and respond to specific motivations. The third element of disposition is ability to act as intended, that is, appropriately connect and apply knowledge and skills to the recognised situation. As a group, students bring dispositions to a task and together frame their work on it.

The theory of distributed cognition "extends the reach of what is considered cognitive beyond the individual to encompass interactions between people and with resources and materials in the environment" (Hollan, Hutchins & Kirsh, 2000, p. 175), making a focus on infrastructure important to understanding student collaboration. 'Infrastructure' is treated here as what students assemble for their knowledge work. Not only tools and technologies, but also processes, ways of working and knowledge work centred on constructed objects. In analysing infrastructure, I concentrate on the "selected" and "constructed" environment (Bandura, 1999) that students build for their group projects. These are (a) selected technologies, tools and information sources to support work, and (b) direct shared construction of concepts and knowledge objects (Nicolini, Mengis & Swan, 2011). The Distributed Cognition for Teamwork (DiCoT) framework, as implemented by Furniss and Blandford (2006), uses a range of measures in the physical layout, information flow and use of artefacts (which represent cognition and coordinate activity), as well as a social/cultural model, to describe the functionality of teams who share knowledge and information. In this paper, I use elements that indicate "situation awareness" (of what has been done, what is happening now, and what is planned) and the immediate "horizon of observation" (what is shared and can be seen and heard) (Furniss & Blandford, 2006, p. 1177). The elements I use characterising groups' infrastructure are: the ongoing shared record; shared conceptual development; visibility of progress and use of artefacts and knowledge objects.

Methodology

I used an ethnographic case-based methodology to investigate the sociomaterial aspects of shared knowledge creation. I used case studies because they allow "the development of a nuanced view of reality," with the understanding that behaviour is not "rule-governed," but complex and contextual (Flyvbjerg, 2004). The seven cases were groups of 3-5 university students collaborating on open-ended assessment tasks in a large metropolitan Australian university. Cases came from two courses in engineering and education (see below). Concentrating on object-centred shared knowledge creation, I video-recorded, transcribed and descriptively coded in-person group meetings, noting actions, artefacts and tools used over the course of the group projects. I also followed groups online, accessing shared spaces and documents, and interviewed 12 of the 27 participants. I produced summary diagrams of actors and objects across each project, and wrote case descriptions, focusing on: actions over time and the resulting changes to shared objects; emergent practice and local adaptation of supporting infrastructure,

including technologies and tools, for group collaboration; and the role and influence of objects in group knowledge creation. Focus was on process rather than grades. Ethics approval was attained.

This paper presents a brief summary of part of my findings, comparing groups' framing and disposition against how they assembled and used infrastructure in their collaborative projects. All names are pseudonyms and groups are named for their course and numbered according to categories for shared knowledge creation. Staff self-nominated tasks and students volunteered groups. Because groups self-selected for the research, they may have been more confident and cooperative than others. The cases were a snapshot of groups in specific circumstances, neither best-practice models nor cautionary tales, producing a useful range of situated examples of group knowledge creation.

The cases

The four education cases (Edu1, EduA2, EduB2, Edu3) were from an assessment task in a first-year-level history and sociology of education course in second semester, worth 30% and completed over four weeks. It gave equal marks weighting to the collaborative process, product and individual reflections. The task required groups to produce a digital artefact in a format of their choice, to answer a 'driving question' they formulated (for example, 'What if all education in Australia was virtual,' Edu1). The artefact would be up to five minutes in length (or non-linear equivalent) and used in a class presentation. Learning design scaffolded group work and stimulated individual and group reflection through reports during the project. Students were required to nominate and use some form of online communication. The novel digital format led all groups to show an interest in being creative and original.

The three engineering cases (Eng1, Eng2, Eng3) collaborated on an assessment task that added up to 85% of their final mark in a second-year course, first semester, focusing on professional practice. Groups researched and created a report on one of several scenario-based problems and presented results in class. Marks were based on output, mediated to some extent by evaluation of individual contribution. Students were given minimal guidance on their projects, with the stated intention of fostering independent learning. Students were expected to apply professional or transferable skills, such as ethics, critical thinking, research, teamwork and communication. Groups Eng2 and Eng1 chose projects aimed at making Australia carbon-neutral in its energy production. Eng2 elected to research nuclear energy generation, specifically nuclear fusion, and Eng1 divided a range of energy sources between members. Eng3 chose an aid project, 'Modernising a remote village in a developing country,' taking on housing as their project focus.

Case findings

In this section, I describe each case in terms of how they framed and worked on their projects, including the infrastructure they assembled and used. Table 1 summarises the findings. Through analysis of their approach to shared knowledge creation, I classified case groups into three loose categories, and present the cases under these headings. I briefly outline all cases, with more detail for category 3:

1. Divided knowledge work–group members were each allocated discrete tasks to be assembled in the final product, with limited shared knowledge creation.
2. Whole group shared knowledge creation–group members worked together conceptually for most of the project, producing a common repository of activity through artefacts.
3. Shared knowledge creation plus individual artefacts–these groups combined shared conceptual development with substantial artefacts created by an individual.

1. Divided knowledge work

The two groups in this section gave each group member responsibility for particular sections of the project and did not organise extra meetings outside scheduled classes. They were much lighter on conceptual discussion than the other groups, except EduB2. Both groups shared some limited conceptual discussion late in projects.

Edu1
This group of three had not worked together before, and showed differing dispositions towards assessment work: Ellis tended to start work early, Jamie chronically postponed work until submission time, and Finley fell somewhere between these. They were inclined to avoid extra meetings and, in their chosen format of an online timeline, they divided sections between members—covering the past, present and future—on the topic of virtual education. Discrete posts along a timeline supported the division of tasks, not requiring shared development of a

narrative; posts were summaries of information sources. The timeline acted as a record of progress: Finley, covering the 'present' section, saw the large number of posts in Ellis' 'past' section and was moved to add more posts. Jamie did not talk with the other group members about difficulties in finding content for the 'future' section. In the final tutorial, the group members did animatedly discuss concepts, referring to experiences with technology from high school, such as the school laptops scheme (covered in a timeline post) and showing educational video channels they used, such as Khan Academy and Crash Course. Finley described them as "videos that I like to follow, but they are not lectures because they are not made by the university."

> Ellis: In your [Finley's] part [of the timeline], you can write how the internet has opened up learning for everyone. You don't need money anymore to go somewhere to learn.
> Jamie: (leans forward to join the conversation) Cause that's online education now, isn't it? I just realised… So there won't be like textbooks anymore, you'll just be like (pauses)
> Ellis: Yeah, yeah. Even like our library, we don't even go to the library.

The students thus generated ideas on future education, but the sense of "open[ing] up learning for everyone," ideas around formal versus informal sources of learning and improved access were not conveyed in the timeline.

Eng1
Eng1 quickly assigned each student one energy source to research and write up. They agreed on a verbal set of parameters to guide the research and for most of the project did not discuss what they found, beyond brief comments. The group discussed online communications options, but did not establish any, partly due to one member's non-participation in social media, and were also unsuccessful in scheduling extra meetings, so communication was limited to their weekly classes. Students tended to work independently in class, often on other, more immediate, assessment tasks. There were a couple of attempts to discuss the project, but the group seemed at a loss as to how to manage this and were prone to tangential conversation. The group had not worked together before and students generally showed some reticence to lead or direct; one group member did take the lead early in the project, but left mid-semester without a word. In the final class, students shared some information about their allocated energy sources. The report was assembled remotely in Google Docs from individual pieces on the last weekend, delegated group members writing introduction, conclusion and connective text.

2. Whole group shared knowledge creation

The three groups under this heading framed their project as an ongoing collaboration between all group members. EduA2 combined individual research with this approach.

EduA2
The EduA2 sense of the situation was place it in a wider setting, relating it to ideas covered in their studies and to increasing professional understanding. They had worked together before, and oriented towards exploring concepts in their topic, the use of popular culture in education. They related discussion to future activities as teachers, drawing on recent experiences as high school students. Louise reviewed English titles she had studied in school, placing them in the context of popularity and relatability as well as a linguistics course examining sexism in texts. Their dispositions were in agreement and two noted the smoothness of collaboration in interviews. They were inclined to share ideas early and were highly engaged and collaborative, willing to put in effort to achieve high marks, including extra-tutorial meetings. They showed abilities in collective epistemic practices: research; exploration of topic; and recording detailed mind maps and notes, deictic reminders of each conversation. They maintained high levels of conceptual discussion in person and online, sharing multiple resources, including news and academic articles, in their private Facebook Group. The group was stretched beyond their usual structured tasks. Two of the group members noted their initial uncertainty: "it was just very open ended, and that was why it took us a while to get going on it" (Louise, interview); "there wasn't really any triggers for, 'You should go this way'" (Sean, interview). Talking with a tutor helped, and they made better progress "once we'd been researching. It was less of a sort of white-wash idea and we got more specific" (Sean, interview). Sean, by connecting research activity with the early stages of problem-solving, was building personal resources in shared knowledge creation. They created detailed common understanding of the issues and so encountered few problems in translating those into their assessment submissions.

EduB2
EduB2 framed the task as collaborative, electing to develop and create a video together about violence in games, but found it difficult to engage together on the problem. A group member suggested that they each research the topic and bring these to an extra-tutorial meeting, but they did not do so and instead relied solely on personal experience for the video. For example, a group member talked energetically about observing racism in games. By

contrast, three of the four students independently researched and wrote a conceptual discussion of their chosen topic in individual reflections, directing effort to personal rather than group achievement. They did not complete research until after the group artefact was finalised, suggesting a different framing of shared and individual epistemic processes. Their use of online communications was limited, and primarily for group coordination of tasks rather than conceptual discussion. They showed scant experience of video production processes, which stymied progress. The topic of racism was quickly dismissed in favour of the perceived 'easier' subject of violence in games. The frame of an assessment task to be completed was more dominant than one of investigation of ideas, and their approach can be classified as surface learning (Entwhistle & Ramsden, 1983).

Eng2
This group of three were members of a larger study group that had been meeting since the previous year; they were highly collaborative and used the same shared Google Doc for dot-pointed notes through to the final submitted report, combined with Skype for remote work. They tended to work with 2-3 members sharing a screen or working simultaneously on the document, finding sources and making sense through discussion of the information they found. They used extra study sessions. Quinn was inclined to learn more about nuclear energy and this informed their framing of the task, which approached technical factual reporting of nuclear fusion, rather than addressing the task problem. They built some limited awareness of the surrounding political and environmental issues. Eng2 were able to review and edit each other's text, "We really didn't care if people edited it… I could see what they were writing and see if I thought it was okay" (Quinn, interview). The group had both an ongoing record of previous work and a clear view of how the shared document was progressing in real time. Work was flexible: Sam worked on a phone while travelling; Skyping with the others aided Jessie's concentration. The group has subsequently re-used this combination of tools and processes in other tasks.

3. Shared knowledge creation + individual artefacts

These groups were distinguished by a strong foundation of conceptual development and detailed artefacts that individuals in the groups contributed towards the group project. The artefacts were based on discussions and extended or added to ideas initiated by the group, building upon and progressing shared work. This pattern offers a way of managing some division of tasks with shared knowledge creation.

Edu3
Three of the four members of the Edu3 group had worked together on smaller activities. In their initial tutorial, they ranged widely over ideas as they agreed on a driving question to guide their video; conceptual discussion continued in subsequent tutorials and through a private Facebook Group. River posted immediately after the first tutorial, dividing tasks and noting the short time left to complete. All group members used Facebook for both knowledge work and coordination: sharing information sources and summaries, organising group meeting times, giving feedback, and posting items for inclusion in the video. Both River and Charlie noted affordances in posting online, of taking time to craft the point they wanted to make, without having to deal with the "four strong voices" of the group during tutorials: "you're kind of distant from the situation so you can give clear comments without trying to regulate what everyone's trying to say" (River, interview). The group referenced the shared online material in tutorials, and online posts recorded ideas.

River and Blake, who had experience in digital media production, appreciated but were concerned by the extended conceptual discussion: they were aware of the time and effort required to produce a video and so pushed for practical decisions. This led Blake to produce a draft video very early to show Blake's understanding of discussed ideas, "I was just concerned with getting the artefact done. And I do think they did listen to that, but they were also very caught up in the ideas of it" (Blake, interview). If it had been an individual project, Blake may have been satisfied with submitting that initial video as final, however, "You've got to handle everyone's ideas and form them into one, and get a thing out of all of that" (Blake, interview). The group continued to expand on ideas, online and in tutorials. After the next tutorial, River asked group members to each produce a storyboard for the video, but was the only person to do so (Figure 1). It included elements from group discussion and individually-contributed items, including images and videos—together with a script and timing for each segment of the video, ready for assembly by Blake, the editor. In effect, the storyboard and accompanying script organised and made sense of the emergent epistemic object of the group. By conscientiously incorporating common ideas and individual contributions from each member of the group, River produced an artefact that was easily understood and accepted, as well as satisfied River's (and Blake's) need for a more practical and definite plan. After a few tweaks during the tutorial and subsequent recording of the voiceover, Blake edited the video according to the storyboard and script.

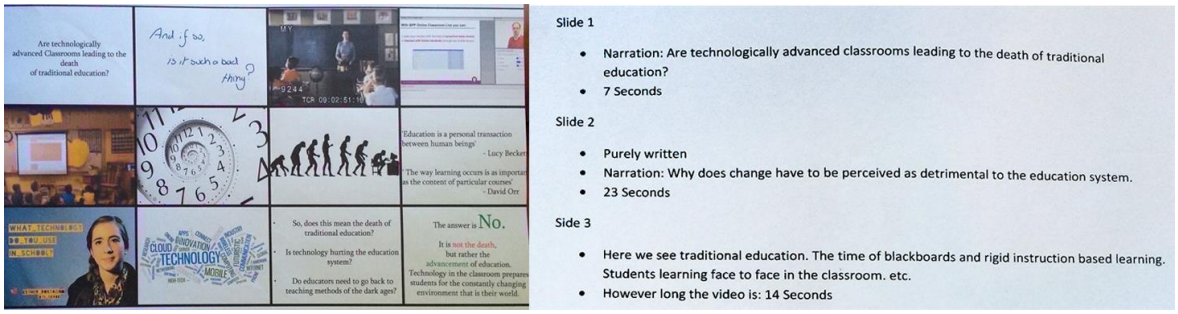

Figure 1: Edu3 storyboard and script by River

Eng3

The Eng3 group of four had the task of designing houses for a remote village. Cameron and Adam formed a central partnership in conceptual and practical development of a solution, partly in response to Cameron's insistence on working together, and possibly influenced by a feeling of urgency due the group's delayed start. The other two members completed tasks assigned to them by the central two. The group did not keep notes after their first meeting, and, using online communication for coordination of work rather than recording conceptual progress, it was difficult for the other two group members not directly involved in discussion to be informed on all aspects of the project. Adam assembled the report just before submission from individual sections emailed to him, so the group had limited opportunity to share and review contributions or the report as a whole.

Throughout, Adam and Cameron used the perspective, "we are an engineering company" (Adam). In contrast to the other two engineering groups, this group produced original design artefacts, a house design and village layout, to answer their identified problem. Collaborative work was almost wholly in person, using paper and pen as well as in-situ computers, with online tools used for incidental communication and file sharing. In addition to using class time, the group also met for an almost-7-hour collaborative session, in which Cameron and Adam sat side by side working on the project. The solution for housing they produced was problematic (e.g. no powerpoints, no kitchen, estimation of materials and costs excluded tools and machinery), however, they showed high engagement with the problem and an inclination to work creatively on it. Information sources used were minimal, mostly online sites covering aid projects, energy-efficient lighting, building materials and construction, and one book on climate-responsive building. Otherwise, Adam and Cameron often relied on personal experience, for example, referencing their Sydney neighbourhoods, when constructing a narrative of the needs of the fictional villagers they were providing with new housing. They used a village layout diagram (Figure 2) and house plan created by Adam as anchors for discussing their solution.

Figure 2: Adam's iterative in-class PowerPoint layouts, with the final layout on the right (Eng3)

Adam started sketching the village layout using PowerPoint in their long collaborative session. At first, he arranged houses in a grid, leading him to say, "Oh this looks like a cage *[expletive]*." Leaning back in his chair invited Cameron's attention. Adam searched Google Images for ideas and Cameron pointed to an image that showed "roads lead[ing] to the middle" that supported his idea on design to support community, which he had talked about the previous week. They discussed ways of rearranging the houses and where to add amenities. Adam worked further on the plan, with Cameron looking on occasionally, but still thought it looked "like a prison." They talked further about how to arrange the new village, and Adam produced a final design at home, incorporating ideas that the two had discussed, as well as Adam's research on orienting housing to the sun.

Summary

Table 1 summarises the cases against elements of infrastructure and approaches to knowledge creation. The groups that showed high levels of shared knowledge creation between the whole group (EduA2, Eng2 & Edu3) combined online and offline conceptual development. Simply having online communications did not guarantee that they were used for conceptual discussion (EduB2, Edu1). With a disposition for dividing tasks (Edu1, Eng1, partly Eng3), groups missed steps in shared problem exploration and knowledge creation. While most projects required some division in roles, the groups that allocated time for group or paired conceptual development and maintained a shared record of the project or used a common document for ongoing work, were in a good position for knowledge creation. By framing the project as requiring a group-devised solution, with progress and contributions visible over time, students had better opportunities to contribute materially, either individually or as a group. Of course, not all groups perfectly fit the categories applied: for example, while Eng3 showed strong conceptual development between two members, they did not use online conceptual development or a shared record, and the other two members were allocated tasks rather than taking part in an overall solution.

Table 1: Comparison of cases on dimensions of shared knowledge creation and infrastructure

Group	Shared conceptual development		Individually-created artefacts	Shared artefactual repository	Visible progress	Pattern of knowledge creation [] indicates category
	Offline	Online				
Edu1	limited	limited	no – but added posts to the timeline	yes, the timeline artefact itself	timeline posts, but one member obscured their lack of progress	[1] Division of tasks, no extra meetings
Eng1	very limited	no	to an extent – worked on separate topics	no	no	[1] Division of tasks, no extra meetings
EduA2	yes – high levels	yes – high levels	no	yes, extensive notes and posts	yes	[2] Deeply collaborative, connect to professional future
EduB2	very limited	no	no – script created as they recorded	no	progress was slow – this was apparent	[2] Surface approach, intended collaboration
Eng2	yes	yes	no	yes: used shared document for writing	yes	[2] Deeply collaborative, ongoing shared work
Edu3	yes	yes	yes	yes, posts and interim objects	yes	[3] Group conceptual development, specific production roles
Eng3	yes – dyad	no	yes	no, but main dyad shared objects and discussion	mostly yes for main dyad, no for other two students	[3/1] Two students shared epistemic work and allocated tasks to the others.

Discussion

To collaboratively solve problems, students need to talk to each other about the problem and identify and explore related concepts; a foundation of problem-based learning (Hung, 2013). In addition, they should create artefacts, such as notes, diagrams, mind maps, images, text—as a group or individually. These artefacts record ideas accessible to the whole group and are a reminder of concepts to be built upon and elements to structure into a solution. This study found contributing factors that stood in the way of students recognising and/or electing to use these strategies and abilities to execute them. How students frame a task, and the dispositions they bring to it, influence the way they create a collaborative infrastructure for knowledge creation, and can help explain why

student groups approach tasks and collaboration differently. While learning design cannot prescribe successful knowledge creation, it can employ principles to support it.

Dispositions and framing

According to Perkins et al.'s (1993) definition of disposition, being able to recognise a situation, being motivated to act, and then having abilities to act in the way indicated, all contribute to the likely approach a student will take to an assessment task, their framing of it. The cases showed that the recognition of the type of situation was key in guiding framing, and that while most groups had little problem with motivation or inclination to engage, their inexperience in shared knowledge creation was a barrier—the aspect of 'abilities' in disposition. The quick division of work in the cases under category 1 above indicates that students did not recognise the task as one that required shared knowledge creation. In dividing responsibility, the groups forfeited much of the shared conceptual discussion that occurred in other groups. However, once individuals had researched topics, both Edu1 and Eng1 groups managed some limited conceptual discussion. By contrast, Eng3 divided tasks, but also recognised the need for a collaborative solution to their problem, which manifested in the main dyad's shared inquiry. EduA2 were unique in the education cases, in expansively framing inquiry in terms of their studies and future careers.

EduB2 group recognised the need for shared knowledge creation, but could not activate shared inquiry, although they were able to do this individually. EduA2 was uncertain how to proceed, but group members found and shared information sources, and persisted with conceptual discussion. The groups consistently weighed up effort against likely effect and impact on assessment criteria; two of the three engineering groups abandoned the use of LaTeX markup, for example. Without experience in group research, EduB2 chose the 'safe' topic, while EduA2's persistence reaped strong conceptual development. Eng2 avoided the main problem of how to provide renewable energy for the country, concentrating on explaining one energy source. Eng1 did not connect the problem to a need for developing a shared solution and could not establish basic project management, although recognising a need for it. The Eng3 dyad worked together on a shared solution, but in isolation from the professional processes and methods to which the task was ostensibly there to introduce them.

Edu3, like EduA2, had worked together on small in-class activities and had some understanding of working together. Edu3 also showed how even limited experience in the target skill, digital media production, can influence how group members view their activity: River and Blake were keen to move conceptual development into a practical frame. Many of the students interviewed had not previously experienced group projects at university and/or an open-ended task. If students are faced with a novel situation, they may fall back on familiar patterns of work and require cues for productive epistemic framing; as did Edu1 and Eng1, and other groups to an extent. The novelty of the education task seemed to help EduA2 and Edu3 form new patterns for shared epistemic work, and the topic of housing was familiar enough for Eng3 to connect to their personal understanding of housing and suburbs. Each of the groups brought particular aspects of productive dispositions to their assessment tasks, and enacted varying levels of shared knowledge creation. The step of connecting abilities, including negative self-perception of those abilities, to task framing can serve to limit first how students frame a problem, in trying to manage scope, and then to limit their efficacy in working on that problem.

Infrastructure

From the start of each project, groups assembled a particular way of working on knowledge: some discussed this explicitly; all also built this tacitly. The emergent quality of infrastructure was evidenced by the cases, as they used similar or identical technologies for differing purposes. The shape and uses of infrastructure generally aligned with how groups framed their projects.

Features of infrastructure helped or hindered group approaches to knowledge creation. Edu1 chose a digital tool that afforded discrete posts and did not require an overall narrative, which supported their original inclination to divide work. Eng1 agreed they needed online communications, but did not establish any, exacerbating the lack of visibility of progress and level of observation between group members. Eng3 also lacked a common repository for their work. All the education cases were required to establish online communications and did so; EduA2 and Edu3 used their online space for conceptual discussion throughout their projects, although EduB2 did not and Edu1 only in a limited way. Even in a very un-scaffolded task, Eng2, with further prospective opportunities to work as a team, added to their collaborative skills by trying out a new set of tools and processes for their project. While mandating particular elements in infrastructure, such as a common file repository and online communications, will not by themselves ensure students create shared knowledge, they can at least help students with functional coordination and establish foundational understanding of how to manage group work, in preparation for deeper collaboration in later projects.

Artefacts

The type and volume of shared knowledge that groups created using their assembled and built infrastructure was important, because this provided opportunity for deeper learning, as students expressed ideas and negotiated meaning and solutions together in knowledge artefacts. For EduA2, created artefacts included online commentary on information sources, mind-maps and notes. Without extensive shared knowledge creation, Edu1, Eng1 and EduB2 group projects generated fewer artefacts during their projects. Although these groups still shared some conceptual discussion, it was not at the level observed in the other groups. Of course, not all ideas appeared in submitted assignments or even interim artefacts—there is conceptual development between students as they talk that is not captured.

I identified individually-created artefacts that incorporated, extended and contributed to the shared knowledge work of a group, especially in Edu3 and Eng3. These artefacts synthesised collaboratively-developed ideas into objects produced by one person. Blake (Edu3) produced the early video to visualise the format of their final product and progress the project. River (Edu3), through storyboard and script, brought together ideas, text, images and videos contributed by individuals or developed in group discussion, forming a blueprint for the final video. Adam's diagrams similarly incorporated ideas discussed with Cameron, and crucially provided a focus for their in-person problem-solving, as the location and shapes of elements in the diagrams prompted questions, reactions, explanations and iterative improvement. Individuals who created the artefacts did so of their own volition when they recognised a need for them: there was no task instruction to create artefacts. By contrast, all groups were instructed to provide a task timeline as a record of their collaboration, however none of the groups used theirs to actively monitor and plan their work.

Design principles for shared knowledge creation

Various principles for supporting students to create shared knowledge are covered in literature (for example, Hung, 2013; Hmelo-Silver, Chinn, Chan & O'Donnell, 2013); the ones outlined below focus on disposition, framing and sociomaterial infrastructure for productive shared knowledge creation.

Multiple opportunities to solve open-ended tasks. Groups should be assisted in developing appropriate dispositions through repeated exposure to tasks that require collaborative infrastructure for problem-solution. Even the most efficient and collaborative groups can be stretched out of their comfort zones, while other students will need scaffolding, such as scheduled class time and methods for problem exploration.

Cues for motivation and framing. Because students take a surface approach in one task does not mean they will take the same approach always (Buckley, Pitt, Norton & Owens, 2010). Consider how the task, its assessment criteria and supporting exercises cue students' framing and motivation.

Appropriate level of challenge. The engineering groups especially lacked foundational skills in engineering practice, but not motivation in learning to use them. The groups were keen to develop professional approaches, but did not show the abilities to identify and develop these independently. The projects created interest, but were too challenging. Structured exercises and resources for supporting relevant professional skills and processes would have been useful.

Guidance and practice in constituent skills for problem-solving. Although they created knowledge, groups' work was not necessarily backed up by strong research and knowledge integration skills. Unless students are confident in their abilities, they may not frame tasks as knowledge creation. Problem exploration was a new skill for groups: some skipped most of this stage. All of the engineering groups, faced with filling knowledge gaps in unfamiliar topics, were in need of support in developing productive epistemic practices. EduB2 took a relatively shallow approach, which fostering ability in collaborative research and video production could have improved.

Low-stakes preparatory group activities. EduA2, Edu3 and Eng2, who had worked together before, were able to work more conceptually and closely, and expressed confidence in each other. They had, or were on the way to establishing, a functional team. The two driving members in Eng3 developed a strong partnership. Students will benefit from activities to familiarise members with each other and develop common frames of action.

Online communications and shared working space. A shared record and visibility of progress helped the groups that framed their project as knowledge creation use their common tools for conceptual development. An online record contributed to the richness of collaboration. Instantiating ideas in objects, notes or individually-contributed

objects, assisted all groups in conceptual development; the groups with fewer shared artefacts or visibility of concepts and progress were less productive epistemically.

Encourage artefact creation. Artefacts were used to solve problems–for Edu3 to enable production of a video and organisation of knowledge and for Eng3 to estimate materials and cost, as well as visualise and design the solution to building a village of new houses. They instantiated knowledge and had a goal. While an artefact for its own sake, such as an unused group planning timeline, is of little value, students should be supported and encouraged in instantiating and sharing ideas. If framing, task conditions and conceptual development align, it should become natural for students to share ideas in artefacts.

Conclusion

Students bring aspects of productive dispositions to assessment tasks. Some will be keen to learn, but need help in accessing related abilities. Students may not detect a need for shared knowledge creation, while others who want to collaborate need assistance in transferring individual skills into collaborative research. Helping students learn to collaboratively solve problems is a long game, as each student will react to and learn differently from each experience. In learning design, evaluation of student work, and in research into shared knowledge creation, consider the dispositions students bring to a task, evidenced in their framing of it and their resulting infrastructure, including the artefacts they create.

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