Towards a Theory of Generative AI in Problem-based Learning

Insights from a Design Experiment at Aalborg University

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Abstract

This article presents a design experiment in which generative artificial intelligence (GAI) was topically integrated into a Problem-based Learning module in a pedagogical study programme with the intention to generate insights for both, future GAI-in-PBL practice and theory. Based on various data (student reports, notes, a focus group interview, transcripts of teachers/researchers' discussions), three design elements were assessed regarding their potential to help students to develop their own learning practices with GAI, and regarding how the emergent practices and dynamics enrich existing PBL theory. The analysis revealed students' weariness, shame and fear for/of using GAI, but also how the PBL process enabled them to develop their own reflective and nuanced GAI practices built on their own learning, integrating community, communication and trust. The experiment also revealed co-knowledge construction amongst students, while

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stakeholders and teachers were seen as figures of authority on how to approach GAI.

Keywords: Generative artificial intelligence; ChatGPT; Problem-based Learning; students; design experiment; exploration

Introduction

Scholars and practitioners currently are not shying away from heralding the potential of generative artificial intelligence (GAI) for learning purposes, praising the technology's advantages as to "better meet students' learning needs, improving their efficiency and grades" (Yu, 2023: 5) by virtue of "its ability to respond to user prompts to generate highly original output" (Chan & Hu, 2023: 2), thus enhancing language learning (e.g., Crompton & Burke, 2023), helping with brainstorming ideas (e.g., Atlas, 2023), or provide customized scaffolding and feedback (e.g., Dai et al., 2023). And while the usefulness of GAI for certain types of learning needs to be acknowledged, it needs also to be stressed that recommendations on how to integrate this technology with learning processes seem to come primarily from a perspective under which learning is being conceptualized as a mainly cognitive enterprise, building on knowledge conceptualizations previously institutionalized.

The present study took offset in a concern that the learning possibilities of GAI heralded at the moment are not fully suited to account for learning in an active learning context such as Problem-Based Learning (PBL). PBL builds on learning conceptions that embrace the sociability, materiality and open-endedness of the learning process, thus opening for understandings of knowledge as socially and contextually constructed (e.g., Hung et al., 2019). Thus, in this paper we are exploring how GAI that can be understood not as a tool for certain learning, but as a technology that is part of the learning process owned by students under those premises.

Previous research has shown that students in PBL environments create their own (divergent) logics and practices when appropriating digital learning technology, often answering to the demands of the PBL-process (Sørensen, 2018). Concomitantly, there is evidence that what guides students' learning processes in technology-enhanced PBL not necessarily is the technology's affordances, but their preferences and interests in terms of modes of studying and interacting (Scholkmann, 2017). Also, students in a PBL-environment have been shown to perceive digital technology useful for amongst others engagement, communication and efficient collaboration (Silin & Kwok, 2016) –

functions that are not necessarily addressed in current scenarios of how to integrate GAI with learning.

To not prematurely follow existing suggestions about GAI-use for learning, the present study followed an open exploratory approach to gain insights into how GAI can be integrated in accordance with active, embedded and problem-based learning principles. The call for integrated and exploratory approaches towards GAI in learning has recently been raised for example by Carvalho and colleagues, who stated that learning in a world in which AI plays a role will need "[p]edagogical practices that emphasize human skills (creativity, complex problem solving, critical thinking, and collaboration) (…) for supporting one's ability to communicate and collaborate with AI tools in life, learning, and work." (Carvalho et al., 2022: 2).

Due to the novelty of the phenomenon, we chose Design-Based Research (DBR) as an approach integrating teacher, student, stakeholder and researcher perspectives (Design-Based Research Collective, 2003). With the design experiment as DBR's preferred method (Reimann, 2011), we infused GAI as a topic in an introductory module in one of Aalborg University's (AAU) pedagogical master programs, where we focussed on students exploring their own and other students' use of the technology. Due to DBR's ambition to contribute to development of both, concrete pedagogical practice and learning theory (Reimann, 2011), the research question we are asking for this article is: *What are theoretically grounded focus points for future scenarios of GAI-PBL-integration based on the insights gathered during a design experiment on this topic?*

Design-based research as methodological approach

DBR as an educational research paradigm

Design-based Research (DBR) builds on the idea of "experimenting to support learning" (Reimann, 2011: 40). A pedagogical intervention is designed and executed under authentic conditions (Anderson & Shattuck, 2012), with the intention of "testing and revising conjectures about both the prospective learning process and the specific means supporting it" (Cobb & Gravemeijer, 2008, after Reimann, 2011: 40). Within that, DBR goes beyond the immediate and short-term adjustment of the didactics applied, but builds on targeted and theoretically grounded data gathering which provides the potential to extrapolate towards a situated theory or learning (Reimann, 2011).

Elements that need to be operationalized in a DBR-study are *iterative cycles* of design, enactment, analysis, and redesign; *collaboration* with practitioners to address real-world problems in authentic contexts; *theoretical and practical goals* aiming to develop theories and practical solutions simultaneously; an

interventionist approach that implements and tests in real-world settings; *rigorous and reflective inquiry* to refine both the design and the theory; *contextual relevance* ensuring that the research accounts for the complexity and context of the environment; *stakeholder involvement* in the design and evaluation process; and *scalability and sustainability* of the interventions (Brown, 1992; Collins, 1992; Design-Based Research Collective, 2003; Barab & Squire, 2004). Moreover, in an educational design experiment also factors such as the specific *educational context* and the *learning theories underpinning the pedagogical approach* need to be made explicit (Campanella & Penuel, 2021).

DBR also been called out for its "messiness" (Hanghøj et al., 2022: 222) when it comes to a clear isolation of influential or less influential factors in the design process (cf. also Dede, 2025). However, the approach's validity can be found in its embracement of "participatory design traditions of Scandinavia" (Campanella & Penuel, 2021: 3) and its potential to "not only produce better interventions but also to transform people and systems" (Hoadley & Campos, 2022: 207) in the sense of "a form of scholarly inquiry" (Bell, 2004).

The design experiment in the present study

A general overview over the design experiment executed for this study can be found in figure 1, while the specific elements will be explained in more detail below.
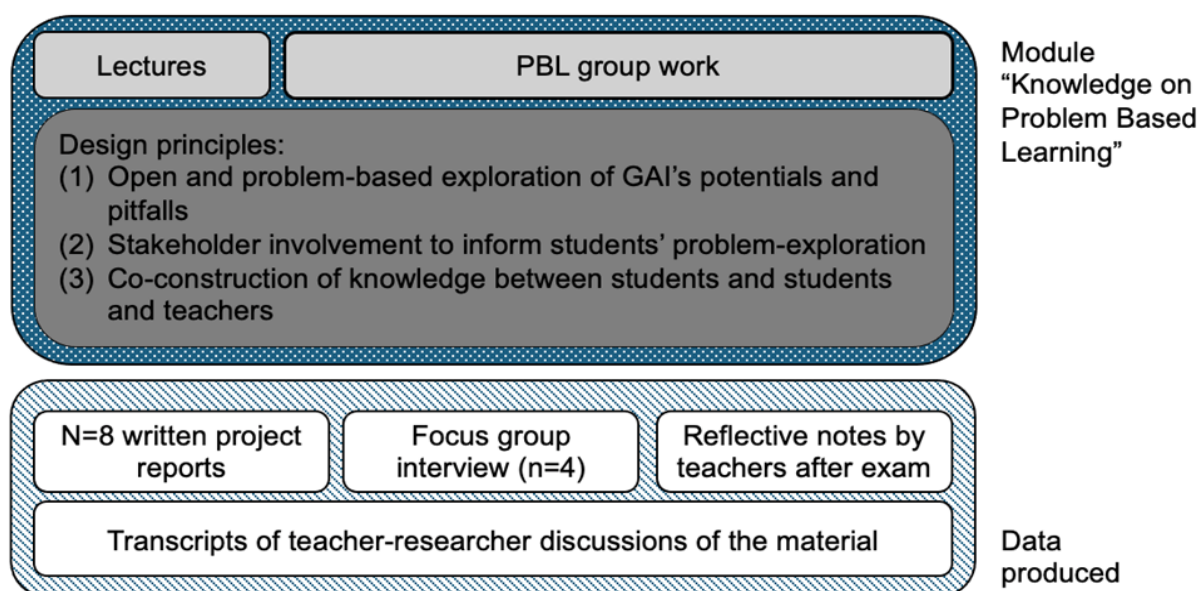

Figure 1. Overview over the design experiment and data produced.

The module "Knowledge on Problem-based Learning"

The design experiment took place at the level of the module "Knowledge on Problem Based Learning" as part of an existing master's degree programme in the Humanities. The program's focus is on learning from both a pedagogical

and organizational angle, and it is studied by students with either university bachelor's degrees or professional bachelor's degrees plus work experience. The purpose of the module is for students to get familiar with AAU's specific PBL approach (Aalborg University, 2015) both practically and theoretically.

The module is conducted in a combination of lectures and parallel PBL project work, accredited for with 10 ECTS in total. Digital technology is addressed in line with the overall set of rules in the department. PBL project work is conducted in groups of up to six students as a minor empirical case study, where the problem to be worked on is self-chose by the group (Aalborg University, 2015). The module closes with an oral group exam based on a written project rapport. The module is offered once a year (autumn term) and in the present iteration was taken by n=60 students.

Making generative AI a topic based on PBL design principles
Dure to its novelty and sudden broad accessibility, in 2023 we as teachers decided to integrate GAI (specifically ChatGPT in the then student-available version 3.5) into the module as a topic based on three PBL design principles: i) an *open and problem-based exploration* of the new technology's potentials and pitfalls for educational processes; ii) the *involvement of stakeholders* to inform students' exploration of the problem; and iii) the *co-construction of knowledge and understanding* as part of the PBL-group work and of the collaboration with the teaching team.

While the first principle primarily was seen as rooted in the general PBL-practices of AAU, the specific operationalization added to the module was a dedicate focus on GAI. ChatGPT was deliberately not presented as a learning tool with fixed properties, but as an object of exploration and learning, with students being encouraged to cultivate their own focus points of interest and problem definitions. This also comprised small experimentations with prompting and didactically facilitated reflections on the answers retrieved. Most prominently, however, the PBL project work was defined as to be focusing on a self-defined problem in relation to GAI and learning.

The second principle was operationalized by dedicating one lecture to an open talk with three visitors: a teacher from a neighbouring program, a digital learning consultant from the institution's Centre for Digitally Supported Learning and a company representative. Those talked about the opportunities and concerns that exist from their perspectives around the use of ChatGPT in education and answered questions by the students.

The third principle was operationalized again through the existing PBL-practice at AAU, where group work is obligatorily supervised and facilitated by a teacher or other person with subject-specific seniority. In addition, this principle

was specifically operationalized by both teachers supervising group work on this assignment being educational technology researchers that also were part of the research team.

Data produced
For the production of data we oriented our study towards recommendations that DBR experiments build on collaborative research approaches (Gorard et al., 2004) and multiple data sources (Reimann, 2011). This meant that a variety of data was secured, namely:

- Eight written *project rapports* by the students
- *Notes* taken after exams by two members of the research team
- A *focus group interview* with four students from different groups
- *Recordings of the research team's discussion* of the material gathered

The corpus of *project rapports* consisted of eight out of a total of n=12 rapports handed in as assignments, as four PBL-groups decided to not consent to their products being used for further analysis.

Notes were taken after exams by the two members of the research team that also acted as teachers and subsequent facilitators on the course. They contained immediate impressions and resonance to the topics discussed during the oral defences of the project-reports and comprised one to two handwritten pages, each.

The *focus group interview* took place after completion of the module with four students on a voluntary basis and followed a semi-structured setup. Questions were directed towards experiences during the design experiment and how this had changed and shaped students' GAI-in-PBL practices. A special element of the interview was the use of picture card material as visual prompts to instigate open and playful communication amongst participants (Glegg, 2019). The four informants were divers in terms of gender, age, educational background (university bachelor or professional bachelor) and work experience outside university (see table 1).

Pseudonym	Gender	Age (years)	Bachelor's degree	Work experience (years)
'Tobias'	male	23	University	2
'Signe'	female	23	University	2
'Marie'	female	27	professional	2
'Karen'	female	46	professional	22

Table 1. Overview of informants with background information.

Recordings of the research team's discussions were made in two analysis meetings, where all four members of the research team discussed the topics emergent from the student reports (meeting 1) and from the focus group interview (meeting 2). The research team consisted of the two researchers that also acted as teachers and facilitators on the module ('researcher 1' and 'researcher 2'); an additional researcher also representing digital educational development aspects due to their affiliation to AAU's respective academic support unit ('researcher 3'); and a research assistant that was integrated as co-researcher due to their recent completion of the program that the module under study was part of ('researcher 4').

Analytical approach

The analytical approach for this study followed DBR's ambition to provide new insights for pedagogical practice and pedagogical theory alike. Therefore, our analysis of the data was guided by a focus on the design principles underpinning the experiment. We conducted an inductive analysis cutting across the various data, meaning that potentially all data could inform any aspect of the design experiment and its underlying theory.

The analysis was rooted in Gadamer's notion of philosophical hermeneutics (Gadamer, 2006), with a focus on the social conditions that lead to interpretations of GAI in the PBL context by both the students and the research team, which were understood as interpretative entities in the hermeneutic process (Højberg, 2014). As 'text' in this analysis we treated all tangible material such as written study rapports and transcripts. However, following research tradition of Digital Hermeneutics (e.g., Capurro, 2010; Chan et al., 2015; Romele et al., 2020), also GAI was treated as textual, meaning that the perspectives students and the research team conveyed about this technology was understood as interpretations in itself.

The analysis was conducted in NVivo, version 14, and resulted in nine main categories with 251 coded references in nine major categories. For the present analysis, references coded under the first five categories ('Students perspectives on GAI'; 'Learning dynamics'; 'Stakeholder perspectives'; 'Co-construction'; and 'Preconceived and changing understandings in the research team') were analysed thematically following sub-questions relating to the three design principles (cf. table 2).

Design principle	Operationalization	Sub-questions
Open and problem-based exploration of GAI in a PBL-environment	• General principles of project-oriented PBL • Integration of generative AI as a topic into lectures • PBL group work centred on GAI as part of students' learning processes	Design: Which *perspectives* and *learning dynamics* emerged when GAI was made a topic in the PBL process? Theory: What are new insights informing theory that argues for open and problem-based learning approaches under a GAI-perspective?
Stakeholder involvement to inform students' problem-exploration	• Invited guests in relation to GAI • Students' own choice of informants for their project work	Design: How did *stakeholder perspectives* play out in the process? Theory: What are new insights informing theory that argues for stakeholder involvement/real-world problem integration in learning processes under a GAI-perspective?
Co-construction of knowledge between students and students and teachers	• Group work supervision by two learning and education technology researchers (also part of the research team)	Design: In how far *did co-construction take place*, and who was partaking in such co-construction? Theory: What are new insights informing theory on co-construction in learning under a GAI-perspective?

Table 2. Design principles, operationalizations and sub-questions.

In the following, the findings of our analysis will be presented in line with the sub-questions relating to the three design principles above. An elaboration of the insights for PBL theory will subsequently be presented in the discussion.

Findings

GAI-perspectives and learning dynamics

The first part of the analysis was based on n=179 references in the categories "Students perspectives on GAI" and "Learning dynamics", together, which were the most frequently coded reference in the material. This resulted in

findings under this part of the analysis needing further differentiation, which was done by clustering them in three overarching topics, which were labeled as: i) *PBL as a way to overcome hesitation and fear towards using GAI*; ii) *emergent GAI-practices*; iii) *anchoring of GAI-integration in categories of personal relevance*; (see table 2). Each topic was informed by different aspects, which will be subsequently illustrated by quotations in tables 3, 4 and 5.

PBL as a way to overcome hesitation and fear towards using GAI

As a first topic regarding GAI-perspectives and learning dynamics there was a notion of the open exploration of GAI helping students to overcome hesitations and fear towards using the technology. Findings here unfolded in a chronological perspective, visualized overarchingly in table 3, where developments can be read from right to left.

From the student reports and subsequent discussions in the research it became clear that many students on the module experienced ambivalence and fear towards the use of the new technology. These fears presented as based on several aspects, such as worries about "correct" use of the technology so as not to be called out for plagiarism, fear of sanctions and expulsion but also fear of learning incorrect facts and losing the ability to think critically (cf. aspect Various fears). Fears seemed also to be tied to students calling for clear regulations on GAI-use, not least because they expressed the desire to take responsibility for their own learning processes (cf. aspect Call for regulations). Moreover, students themselves elaborated on their initial challenges regarding GAI during the focus group interview. Here, participants expressed that they initially were lacking GAI-knowledge and competences (cf. aspect lack of GAI knowledge and competences). Moreover, they conveyed that several of them initially experienced using GAI as somewhat shameful and to be hidden from each other (cf. aspect GAI use as shameful).

During the focus group interview students also engaged in a discussion how the module had changed their initial view on GAI. They reported that they had developed a more open and explorative approach based on the PBL-process. For example, they elaborated how the explorative approach had initiated openness for the different possibilities of the technology, and that using ChatGPT was not to be considered "cheating", necessarily anymore (cf. aspect Development of an explorative approach). There was also a sense of added nuance and "demystification" (cf. aspect Added nuance and demystification). Finally, several students expressed their interest in developing competences on how to use it beyond what they already knew how to do by themselves (cf. aspect Wish for competence development).

Various fears	Call for regulations	Lack of knowledge	GAI use as shameful	Development of an explorative approach	Added nuance	Wish for competence development
[T]here is a lot of fear (..). There is a lot of focus on the poles right and wrong; that you can use [ChatGPT] correctly and that you can use it incorrectly. (…) [S]tudents are afraid of being accused of plagiarism, or that they can risk being thrown out of their studies and of sanctions if they use it incorrectly. And then [also that] you can learn something wrong if you "don't think about it carefully" (…). Then there are also worries about the students losing their ability to think critically (…). (researcher 4, meeting 1)	I think gennerally students find that [Chat GPT] is positive, but it would be more positive for them (…) if there were guidelines that they feel they need to be successful [when using] it. (researcher 3, meeting 1)	[B]asically, it was about my ignorance, I think. That I actually didn't know what [chatGPT] was. (…) At the time I also thought it was cheating, because I didn't know what it was. (…) I didn't know enough about it." (Karen, focus group)	Yes, it's a bit shameful. That you hide behind something and are ashamed of it. And something like: Well, maybe you should admit that, too? Have I used it? (Tobias, focus group).	I (.) think that the whole process we had around ChatGPT, and (...) having to go out and investigate, or, just (..) to have an open discussion about ChatGPT and how people can use [it], (..) kind of opened my eyes to, okay, you can actually use it for other things than just [cheating]. In other words, you can actually do more than just generate a text that you then put into an assignment. Well, it can be a work tool. (Marie, focus group)	And then it was just nice to be able to talk about it, and find out what is it really, get it demystified, and find out, okay, I can actually be a little more comfortable in it, much more confident in it (...) (Marie, focus group).	Now [that] you mention teaching. (...) How can we use [GAI] when we are out (…) in the process of fieldwork? (…). So, how can it become an element of our learning? (Tobias, focus group)

Table 3. Aspects under topic 'PBL as a way to overcome hesitation and fear towards using GAI'.

Emergent GAI-in-PBL practices

In addition to the developmental perspective, students also began to engage in new practices integrating GAI into their PBL processes. Aspects and quotations underpinning this topic can be found in table 4.

It became obvious that students began to engage in community building with each other around the use of GAI (cf. aspect Community around GAI). This went closely together with the emergence of a shared language to navigate the use of the technology (cf. aspect Shared language). Intertwined, yet separate, students also expressed the importance of being transparent in PBL-groups about GAI-use to establish consensus and trust with fellow group members (cf. aspect Building trust). Regarding the call for regulations, several students conveyed that they had started to integrate GAI-use into their PBL group contracts. By that the impression emerged that what had previously been understood as a task to be cared for externally, had at least partly gone over to an internal group-based overtaking of responsibility (cf. aspect Group-based regulation).

Moreover, students also discussed how they concretely were using GAI (aspect GAI use) and where they perceived limitation of the technology (aspect Reflections on limitations). Students were seeing advantages of using GAI as part of their project work in gaining a better overview and help elaborate on learning content, while they saw limitations in it not being able to substitute a human project supervisor, as it was lacking understanding of context and was perceived as not being able to challenge them in unexpected ways.

Community around GAI	Shared language	Building trust	Group-based regulation	GAI use	Reflections of limitations
[T]hat I wasn't alone with it, and that I didn't need to sit and be ashamed that maybe I hadn't looked into it, or maybe I didn't know what to use it for. But that I could go to [that] we were [using it] together (…). (Tobias, focus group)	[T]hat's also kind of what we found out in our project (…) That it was a good idea to have the conversation about how to use [chatGPT]. Both we in our group talked about it, but also those we talked to [talked about it]. It was very much like: Well, we need to know when it has been used. And how, because we would like everyone in the group to be informed. (Signe, focous group)	It can easily create mistrust if you are not very transparent about it (..). You also have to be sensitive (…) I think it's (…) also about how safe you feel in the group (Marie, focus group)	And we now create our own guidelines for how we use [chatGPT] and how we feel about it, and how we will subsequently use it. (…) now it is actually stated as part of our group contract. So if we (..) want to use chatGPT, then we have the dialogue about it, and we make the others aware of it. So yes, I just think it's also interesting that now it's part of the process. (Tobias, focus group)	I think in the future I will be able to use [chatGPT] as a sparring partner, or someone who might just be able to help elaborate on some texts, or translate a text, or explain some concepts in a different way. I don't think I'll use it to write anything for me. But I think I'll use it as a help. (Karen, focus group)	This thing about [ChatGPT] not being able to make you reflect (...) as a supervisor would. Yes, this self-reflexive mindset that you have at a university - at least here at Aalborg University - it can't really come up with [ChatGPT]. (Signe, focus group)

Table 4. Aspects under topic 'Emergent GAI-in-PBL practices'.

Anchoring GAI-integration in categories of personal relevance

In addition to the two topics above, a third topic emerged from the analysis on students' GAI-perspectives and learning dynamics. Students seemed to root their integration of GAI not in narrow learning goals but rather found motivation and inspiration in categories of personal relevance, as visualized in table 5.

Student 'Karen', for example, reported to make use of GAI specifically to help her understand theory that she was not sure she grasped during class (cf. aspect Specific use). Student 'Signe' notably conveyed that her GAI-use primarily was inspired by "fun" activities such as finding recipes, however also because she still felt hesitant to use it for study-related purposes (cf. aspect Private use). In addition, 'Marie' elaborated on the relevance of learning about GAI not only as part of one's own competence development but as part of the program they were studying, where they, as learning experts, would be expected to be knowledgeable about the technology's role for learning and cheating, respectively (aspect Future professional relevance). Moreover, 'Marie' engaged in some elaboration of transfer between what she experienced as part of a PBL group and what she could see as potential use of GAI in her previous professional field (occupational therapy, cf. aspect Transfer).

Specific use	Private use	Future professional relevance	Transfer
I [would never use ChatGPT] to write anything for me (.). But (.) I often use it in relation to when we read some theory (..) for example now we had this with [names specific theory], right? Where I sit and read it, I ask [ChatGPT], can you try to explain [this theory] right? Well, then it's a help for me, because then I get it in a different way. I am well aware that some of it may well be wrongly worded, but it is still such a support for my understanding. (Karen, focus group).	I don't use it that much for [study] tasks or anything like that. More for fun, for example if I need to find some recipes or if I need to do something. Because I [don't] want to know how to [use it for study-related tasks]. (Signe, focus group)	[Knowledge about GAI] is incredibly relevant in relation to our study with learning and change processes, because we have to deal with learning and change processes. And presumably, many of us will come across some form of teaching where you have to stand in front of students. Here, it is quite important that you know (…) how chatGPT can be used. So we also know what to pay attention to so that we can see how [students] have used it. And whether they have used it in the right way. (Marie, focus group)	Once I found out what [chatGPT] could do, I couldn't stop clapping my (..) hands in relation to occupational therapy. Because there are a lot of supported housings that have people who find it difficult to structure a task and plan (…) Here people can use [chatGPT] independently and instruct it how detailed [a plan] should be. (Marie, focus group).

Table 5. Aspects under topic 'Anchoring GAI-integration in categories of personal relevance'.

Stakeholder involvement to inform students' problem-exploration

Findings on the second design principle are based on n=11 coded references in the category 'Stakeholder perspectives', which had a much lower number than the references underpinning the analysis for the first design principle. Accordingly, the findings presented in the following emerged as more focused and without further sub-topicalization. However, also for design principle 2 several aspects emerged as underpinning insights into the sub-question which stakeholder perspectives played out in the process (cf. table 6).

As a first aspect it became obvious that the students were incorporating the experience of other students as their stakeholder perspectives, exclusively. This could primarily be seen in the project reports, with all eight of them taking this perspective, despite students being presented with a teacher's, a digital consultant's' and a workforce representative's view during the lecture. However, as became clear during the focus group interview, given the newness and perceived uncertainty of the situation, students decided to focus on their own leaning about GAI use by researching other students' use of the technology. This was explained for example by 'Karen' during the focus group, who pointed out how by interviewing students from another program her PBL group learned how to use ChatGPT in new ways (cf. aspect Other students as the primary source of reference).

The perspective of the original stakeholders brought on to the module got incorporated into students' learning processes under a role model perspective. For example, during the focus group, 'Marie' pointed out that the fact that the stakeholders were not as hesitant towards the technology as students themselves felt they had to be gave inspiration to here to be more open in exploring GAI as part of her own learning processes (cf. aspect Stakeholders and teachers as role models). This was supplemented also by discussions in the research team, where it became obvious that also the decision by the teachers to make GAI a topic in the module served as a model how to exploratively approach it.

Other students as the primary group of reference	Stakeholders and teachers as role models
[With] the group that we were talking to, they were [engineering students] who just had complete control of [chatGPT], and they almost taught us about the various plug-ins you can get for it. (T)hey put in their module descriptions (…) and then everything you can ask about it and 'play ball' [with it]. Well, it's crazy. I don't think I'll ever go that far, but I actually really think it was fascinating. (Karen, focus group)	[W]hen we were presented with the case, I was just so incredibly surprised that there were three people who had a challenge with chatGPT, but all of them were actually relatively positive towards it. It surprised me a lot, especially when it came from the education side (*laughter in the background), because I think it was such cheating. (Marie, focus group)

Table 6. Aspects under topic ´Stakeholder perspectives'.

Co-construction of GAI-knowledge and practices

Findings on the third design principle and related sub-questions referring to the intended co-construction of knowledge between students themselves and students and teachers, the analysis was based on n=14 references coded in the category 'Co-construction', supplemented by n=18 references coded in the category 'Preconceived and changing understandings in the research team'. Again, these categories were coded substantially less often than the categories relating to learning perspectives and dynamics, which consequently resulted in fewer aspects and no sub-topics to come out of the analysis, as can be seen in table 7.

Throughout the analysis it seemed that co-construction between students was experienced as closely intertwined with the aspect Community around GAI (section Emergent GAI-in-PBL) and with the aspect Other students as the primary group of (section Stakeholder perspectives). Coded as co-construction, several references from both the focus group and researchers' second meeting related to students engaging in mutual discussion about GAI, with actions such as referencing each other or learnings they took from other people in their PBL-groups (cf. aspect Co-construction between students). Co-construction with teachers on the other hand could primarily be seen as a practice where students took inspiration from teachers, but no indicators of longer-lasting mutual collaboration between the two groups on students' understanding of GAI could been found in the material (cf. aspect Teachers as inspiration).

Co-construction between students	*Teachers as inspiration*
I was in a group with someone who came directly from another bachelor's degree, and they had used [ChatGPT], and it was something with some PowerPoints, and summaries (…) and (..) it was (..) nice that we could talk about it. (Marie, focus group]	When we wrote our project, with [researcher 3] as our supervisor, [they] also brought the perspective that there are young people who use [G]AI on Snapchat to have a conversation with a friend and for being together with others. (…) (Tobias, focus group)

Table 7. Aspects under topic 'Co-construction of GAI knowledge and practices'.

Discussion and implications

The present study was based on the concern that many learning advantages ascribed to GAI today are neglecting perspectives of active and open learning, such as Problem-Based Learning (PBL). Thus, in this paper, we dove into an exploration of how GAI could be understood not as a tool to reinforce certain types of learning, but as a technology that becomes interwoven with learning

processes owned by students. For that, we followed a Design-Based Research (DBR)- approach, where, as a design experiment, we infused GAI in learning as a topic of exploration into an introductory module in one of Aalborg University's (AAU) pedagogical master programs. We collected data such as student reports, interviews, field-notes, and recorded discussions in the research team with the ambition to contribute to the development of both, pedagogical practice and active learning theory on GAI in the context of PBL. The research question guiding these efforts was: *What are theoretically grounded focus points for future scenarios of GAI-PBL-integration based on the insights gathered during a design experiment on this topic?*

In the following, we will sum up on this question with as specific focus on how our findings contribute to theory on learning in a PBL context. We will also raise the question in how far findings on the three design principles tested, i.e. the open and problem-based exploration of GAI in a PBL-environment, stakeholder involvement and co-constructive processes, can eventually enrich an emergent theory of GAI-in-PBL.

Discussion of the results in relation to PBL learning theory

Open exploration of GAI in a PBL-environment

With respect to the findings on to the first design principle, it seemed that the open exploration of GAI as part of students learning in a PBL context helped to decrease students' initial hesitations towards the technology. Specifically, the PBL-process opened spaces for exploration without shame of not-knowing and fear of being called out for academic misconduct. Students expressed growing degrees comfortability when experimenting with the technology as part of their learning processes. They also seemed to have developed a more nuanced understanding of its possibilities and felt more comfortable to express their desire to learn more about how to use GAI in their learning journeys (cf. PBL as a way to overcome hesitation and fear towards using GAI). In addition, the analysis showed a set of emerging GAI-in-PBL practices by students themselves, such as building a community around GAI, finding a shared language and mutual trust, as well as negotiating rules for using GAI in their PBL-work, specific scenarios of GAI use and emerging reflections on the limitations of applying GAI in a PBL context (cf. Emergent GAI-in-PBL practices) Finally, it became obvious that students rooted their reflections on their emerging GAI-practices in categories of personal relevance (cf. Anchoring GAI-integration in categories of personal relevance).

All these findings resonate closely with learning theories and research underpinning PBL and the value of an open and self-directed learning process (for an overview cf. e.g. Holgaard et al., 2017; Milner & Scholkmann, 2023). By giving problem ownership, including ownership of problem definition, to

students, they were able to shift from a teacher-led to a self-defined topical exploration of GAI, and to develop strategies for future use of the technology (Thomassen & Stentoft, 2020). Also, learning and knowledge-making became social rather than transmitting (Cambridge et al., 2024).

What the present design experiment added in terms of a GAI-perspective was, firstly, the outstanding role of emotions. Emotions have been brought to learning researchers attention more frequently in the last years, as they are crucial for the ways students engage in learning processes (e.g., Quinlan, 2016; Pekrun, 2019). Also, students expressing concerns towards GAI-use due to fear of legitimacy, learning and social belonging has been demonstrated in at least one other study so far (Chan & Hu, 2023). So, while PBL-related learning theories still seem to not have engaged with this crucial aspect, our findings point towards them having a strong influence on the PBL-process (also in relation to other aspects such as the role-modelling of teachers and stakeholders). Related to GAI-in-PBL specifically, emotions of caution might not be out of place given the inherent intransparency of the technology. As they can help students to build a differentiated and adequately critical attitude, they should be incorporated into an understanding of students PBL-processes under the premise of students learning to think critically and reflectively (Lolle, Scholkmann & Kristensen, 2023).

Secondly, both the emergent GAI-in-PBL practices and the fact that students were tying their GAI-exploration to what felt personally relevant to them confirm and amend findings on students' divergent and situationally practices of digital tool use (Scholkmann, 2017; Sørensen, 2018). They also resonate with a recently published study demonstrating that also in more 'traditional' forms of teaching students tend to pivot towards their own, sometimes 'hidden' practices of GAI-use (Corbin et al., 2025) – practices that were openly encouraged in our design experiment. By that, the findings potentially support amending PBL learning theory with an acknowledgement of the "messiness" that GAI is bringing into learning processes (by not being fully predictable), which was met by students by seeking for what mattered to them as a strategy to navigate this messiness.

Stakeholder involvement to inform students' problem-exploration
Regarding the second design principle, the findings indicated that what was intended in the design experiment did not fully live up to the expectations. Instead of choosing between the various stakeholder perspectives the students were presented with, students unanimously focused on other students' GAI-experiences as an offset for their explorations (cf. section Stakeholder involvement to inform students' problem-exploration). However, it must be acknowledged that in PBL learning theory stakeholder involvement is most often operationalized by a longer-term cooperation with external stakeholders (Holgaard et al., 2021), and not a single session in which different stakeholders

presented their perspectives. Therefore, it seems what students did was a logical choice under an unprecise operationalization of the design principle which would eventual call for refinement in future iterations of the design experiment (Design-Based Research Collective, 2003).

However, the accidentally poor operationalization may well have resulted in new insights to amend PBL learning theory under a GAI perspective: Firstly, they add to the perspective discussed above, that under a condition of uncertainty, students seemed to revert to a perspective closes to their own. Secondly, what stood out clearly was that the stakeholder perspectives served as a cue for contextualization of the GAI-phenomenon. This finding draws attention to the role of authority figures in the PBL-process, which for the students seemed to provide cues on how to interpret the problem. While the PBL-literature generally tends to understand PBL-learning processes as a transfer of power and authority from teachers to the PBL-group (Duek, 2000), it has recently been pointed out that also in the seemingly "democratic" PBL-process the dominance of the lecturer as an authoritative figure prevails due to the uneven distribution of power in the educational system (O'Brien et al., 2022). Considering the advancement of PBL theory, these findings therefore add to the growing number of researchers calling for re-visiting the assumption of the PBL-arena as a power-equal and democratic space. With respect to GAI specifically, they also call for a deeper consideration who in students GAI-use is constituted as figure of authority. As public discourse around the non-neutrality of AI is evolving (Hare, 2022), students' desire for orientation regarding responsible AI use especially in the open-ended PBL process should not be dismissed preliminarily, but made a vital part of both GAI-in-PBL theory and practice.

Co-construction of GAI-knowledge and practices
Regarding the third design principle, the findings revealed co-constructive processes to take place mostly amongst students themselves and thus intertwined with other community-building and language-making aspects in their GAI-practices. Co-construction with teachers happed only very limited, however accounts of teachers inspiring student perspectives and reflections on GAI in learning occurred in the material (cf. Co-construction of GAI-knowledge and practices).

Again, these findings resonate with aspects already elaborated above, and confirm PBL theory in that they provide evidence for co-constructive knowledge professes in student groups (Lee et al., 2017). Moreover, they supplement the arguments made before for a future integration of authority as a topic in GAI-integrated PBL. Finally, the thematic overlap in some of the findings add to the argument that a clear separation of design elements might not always be possible in PBL (Hanghøj et al., 2022).

Limitations

It must be emphasized that the available results were collected with a group of master's students in a pedagogical programme. Thus, it cannot be ruled out that this group's particular view of GAI has influenced the analysis' findings, e.g. in relation to the focus on the emotional and social rather than the strategic or technological. Furthermore, this study was based on the knowledge and competence status of all the actors in the period summer 2023 – spring 2024, where, for example, concerns about cheating in the use of G-AI emerged. In addition, it cannot be ruled out that the voluntary participation in the focus group interview produced specific results. Finally, this study has not used a contrasting research design, which means that the results in relation to the PBL pathway must be considered with reservations for possible self-confirming trends.

Conclusion

What the present study and the design experiment have brought to the fore was that an open, exploratory PBL-approach was in fact able to add nuance to the picture of what learning might mean under a GAI-perspective. Adding to the potentialities of GAI *for* learning vented in part of the literature to date, the present study brought to the fore how practices of learning *with* and *about* GAI can be instigated through active student-led exploration. Moreover, the analysis indicated that such practices amend PBL theory in that they alert us to hitherto overlooked aspects of the PBL-learning process under a GAI perspective – specifically, the influence of emotions elicited by the technology, students' being guided by their immediate learning needs and the question of role-models and authority in a GAI-entangled PBL process.

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