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Fostering Computational Thinking and Design Thinking in the IB PYP, MYP and DP

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Executive Summary

1. Context and Scope

The IB Research Department commissioned this study to contribute to the innovation and improvement of IB curriculum and teacher professional development, in light of the global education area of competence development for the 21st century. The constructs of Design Thinking (DT) and Computational Thinking (CT) have been recognized by many as being critical 21st century competencies that underly students' long term educational and career success. Design thinking is said to lie at the heart of productive creativity and is recognized as a key value in many industries. Computational Thinking is seen as a basic understanding of how computers and technologies work, including software, programs and algorithms, and debugging processes, as well as more abstract processes like problem decomposition.

As many other educational organisations at the global level, the IB recognized ambiguities in the definitions and applications of these terms within the scientific literature and wished to gain clarity about those definitions for IB stakeholders. Another objective of this study was to identify some of the best practices relating to the integration of DT and CT within curriculum and assessments, as well as teacher practice and professional development. The IB also sought to understand how DT and CT are currently represented within IB courses and programmes, as well as any challenges confronted by teachers in their inclusion of DT and CT in their current teaching and assessment practices. Finally, the IB was interested in receiving any specific considerations that may provide guidance to future curriculum development and implementation practices.

The authors of this report bring a wealth of experience as academic researchers of these constructs. They were selected in the summer of 2018, based on their proposal to address four research questions:

- *What are the current definitions of CT and DT, including any research of learning progressions, assessments, curriculum integration approaches, and teachers' knowledge, practice and professional development?*
- *How do IB courses and programmes currently incorporate CT and DT in their guides, assessments and teacher support materials?*
- *How do the IB teachers understand DT and CT, and support their integration within their courses?*
- *What are some key challenges confronted by IB teachers, in terms of implementing CT and DT, and any considerations for supporting their future success?*

2. Research Method

The study included three primary areas of work:

- **A literature review** with the aim of establishing working definitions of DT and CT, as well as understanding the relevant learning progressions, assessments and teacher professional development;
- **A curriculum audit** of selected courses, to reveal how DT and CT are integrated within and across the programmes;

- **A survey of teachers** to gain insight into how IB teachers understand these constructs, how they accommodate them within their curricular designs, and any challenges they perceive regarding the inclusion of DT and CT.

This work was performed over the ensuing two years, with several key milestones including the delivery of a preliminary literature review, coordination of the survey with IB Research, and several rounds of feedback and guidance in preparing this document.

Literature review

To conduct the literature review, a search was performed of research papers published since 2006 in major educational research databases, which generated 189 unique relevant papers for CT and 201 unique relevant papers for DT. We then applied three criteria to select the essential and highly informative papers for this review: (1) if CT/DT were the phenomenon of interest or primary learning objective; (2) if the studies or perspectives offered unique, generalizable insights on the conceptualization, operationalization, assessment, and teaching of CT/DT; (3) if the studies or perspectives generated actionable knowledge for classroom practices. This resulted in 113 papers for DT and 100 papers for CT, with 28 papers that were common to both. We examined four themes: (1) Definitions of DT and CT for K-12, including learning progressions; (2) Assessment of DT and CT; (3) Learning contexts and environments; and (4) Teacher practice and professional development.

Curriculum audit

To address the research question about how DT and CT are currently included in the three programmes, a curriculum audit was performed by reading and coding selected courses and program-level documents according to our working definitions. The coding focused on three elements of each course: (1) the course guide, (2) the teacher support materials and (3) selected assessments and specimen papers. This analysis also sought to identify opportunities where DT and CT could be included, or where guidance could be improved. Six courses from the DP were coded: Chemistry, Physics, Geography, Computer Science, Design Technologies, and Mathematics (Applications and Interpretation). Four courses were coded for the MYP: Sciences, Design, Individual and Societies, and Mathematics. For the PYP, the Learning and Teaching document was coded, as well as the Scope and Sequence documents for Mathematics, Social Studies, and Science, and the Technology Integration document. The documents looked at included course guides, selected teacher support materials and assessment specimen exams and/or assessment sections of the PYP.

For each course, or Scope and Sequence document, subsections of the relevant documents were coded for the *Presence* (explicit, implicit, none, or not applicable) of all dimensions of the working definitions. Each subsection was also coded for *Guidance sufficiency* (sufficient, insufficient, or none) concerning each of these dimensions, as well as any *Opportunity for linking to DT/CT* (high, low or not applicable). Open notes were also maintained for each course, regarding the strengths, weaknesses, and opportunities for improving the course with regard to its inclusion of CT and DT. All of these codes and notes were compiled within the same Excel coding sheet, which became the basis for further analysis. A summary was first prepared of all codes for each course, then synthesized across all courses for each programme. This approach provided a set of summary statistics that could reveal the basic presence, guidance, and opportunities for inclusion of DT and CT within the various IB Programs.

Survey of IB teachers

To address the question of how IB teachers understand DT and CT, and implement these constructs into their courses, a survey was developed to ask teachers about (1) their level of understanding of DT and CT definitions, (2) their confidence in how well they are integrating CT and DT into their courses, and (3) the degree to which they have succeeded in integrating DT and CT. Open ended questions were also included to ask *how* they are integrating DT and CT, as well as any obstacles they perceive in adding DT and CT into their courses. Surveys were provided in all three IB languages: French, Spanish and English. For the DP, the survey was sent to 1024 school coordinators, to be forwarded to teachers of the courses we were auditing. 785 complete or partial responses were received, with 92% (719) coming from teachers and 8% (66) from coordinators. The MYP survey was sent to 192 school coordinators, who forwarded it to their teachers. 298 complete or partial responses were received, with 91% (272) coming from teachers and 9% (26) from coordinators. The PYP survey was sent to 581 coordinators, who forwarded it to their teachers. 513 complete or partial responses were received, with, 83% (425) coming from teachers and 17% (88) from coordinators.

Surveys were analyzed by first examining teachers' responses to structured questions about their level of understanding, to reveal basic levels of understandings and look for patterns across several variables (course topics, teachers' years of experience, types of school, and geographical regions).

A subsequent qualitative analysis examined teachers' responses to the open-ended questions, to inform an understanding of how CT and DT are embedded within their courses. The entire corpus of responses was read for each programme, including 3355 records for each of the 2 items coded (6,710 total items), with a sample of representative items then selected for an open coding of ideas and approaches. An idea was defined as some relevant example or instantiation of the teachers' responses. The sample comprised 180 responses for the DP survey, 126 items selected from the MYP survey, and 118 items selected from the PYP survey. English, Spanish and French language items were read for content, and a representative number of items from each was included in the sample.

3. Main Findings

This section describes the main outcomes of the study, presented according the three main areas of work: (1) A literature review; (2) A curriculum audit of selected courses; (3) survey of teachers.

3.1 Literature review

The literature review addressed four specific aspects concerned with DT and CT, with an eye toward those most relevant to K-12 practices: (a) Definitions; (b) learning progressions, assessment and curriculum integration; (c) learning contexts and environments; and (d) teacher knowledge, practice and professional development.

(a) Definitions of DT and CT

The first area of inquiry for the literature review was concerned with the definition of DT and CT. Three main findings are as follows:

1. Most definitions of DT and CT emphasize the importance of open-ended problems or projects that students must solve through collaboration, creativity and design. While there are many definitions, and they often focus on adult learners in the workplace, they typically include an emphasis on open ended problem solving, collaboration and creativity (Buchanan, 1992). Many other definitions of DT refer to a common "Design Cycle" (e.g., Bequette & Bequette, 2012). Industry groups as well as K-16 educators (including the IB) have adapted the design cycle for specific programs and purposes. With regard to CT, exemplary case definitions are The Computer Science Teachers Associations (CSTA) and the International Society for Technology in Education (ISTE). They formed a task force which identified core concepts and capabilities including data collection, data analysis, data representation, problem decomposition, abstraction, algorithms & procedures, automation, parallelization, and simulation (Barr & Stephenson, 2011).

2. Many activities and resources that include DT also include CT (and vice versa) such that the two can be considered as mutually reinforcing. Because DT and CT have many common underlying dimensions (e.g., emphasis on open-ended problems, collaboration and creativity), activities and resources that include one of the two competencies often include some degree of the other. For example, a data-driven design project where students examine patterns of school attendance around the holidays and devise their exam study plans will engage both CT and DT in the creative solution of open-ended problems. It will then engage further dimensions of DT and CT, to a varying extent, depending on the specific nature of the curriculum and how it was implemented in the classroom.

3. Working Definitions of DT and CT that will guide the study. Based on the literature review findings, the following working definitions were articulated, including a set of constituent dimensions or sub-skills that are provided in Section 1 below:

- ***Design Thinking:*** A form of thinking in which learners collaboratively develop creative solutions for open-ended, unstructured problems. Creative, user-centered approaches sit at the heart of design thinking, and require students to develop skills in creativity, empathy, systematic thinking, and to communicate in the language of design, while progressing through iterative cycles of design, building, testing, and redesign.
- ***Computational Thinking:*** a particular form of problem solving and reasoning in which the learner addresses open-ended problems to formulate the problem in such a way that it's solutions can be represented as algorithms that can be worked through either by computers or humans. Complex problems can be decomposed into simpler ones, whose solutions can then be assembled together to solve the original problem. Such algorithmic solutions often require the use of abstract representations of the problem (e.g., using models, equations and simulations) as well as the organization and analysis of data that is based on those abstractions. Once the algorithms have generated some solution, students continue iteratively to check the outcome (i.e., debugging) and improve their solution. While this process underlies most computer programming, the strategies, patterns, and techniques of computational thinking can be applied to a wider class of problems and areas of daily life (e.g., coordinating a complex schedule or organizing our daily routines to be more efficient).

(b) Curriculum Integration and Learning Progressions

The second area of inquiry for the literature review was concerned with curriculum integration, assessment and learning progressions. Three main findings are as follows:

1. The most effective curriculum design strategies are those that address CT and DT explicitly and employ project-based or design-centred approaches. Activities that integrate DT and CT are frequently reported as being multidisciplinary in nature (e.g., within STEM projects) and even entail collaborations amongst teachers from different courses. Assessments can also be cross-domain, with two or more teachers from different courses evaluating the same student projects, according to their respective criteria. There is an overall lack of comprehensive, scalable assessments for DT and CT, partly because the definitions are still being formulated. Effective assessments are often described as formative in nature, providing teachers with a source of insight into students' thinking that can help shape their subsequent instruction.

2. DT and CT are described as competencies (ways of knowing and learning) that students acquire and apply during curricular engagement. Many scholars describe DT and CT as competencies that will serve students in learning across disciplines and throughout their lives. Rather than specific skills or bodies of knowledge to be learned, these are *ways of knowing and learning*. And as such, it is important that teachers see them not as topics to "cover", but rather as a means of covering topics. Through participating in DT and CT oriented activities, students build connections between topics, deepening and extending their understandings. Design and computational thinking can offer many effective forms of inquiry, helping students achieve deep levels of understanding by exercising collaboration, communication, creativity, algorithmic reasoning, and strategic problem solving. Thus, by employing such an approach, teachers are not only ensuring deeper learning within and between disciplines, but also the development of important 21st century competencies. In studies of how to integrate DT and CT within the curriculum, the constructs are typically highlighted as explicit goals for learning and teaching (e.g., Repenning et al., 2015; Vallance & Towndrow, 2016). By mixing such an explicit treatment with a more infused or immersive one, students and teachers become more aware of the importance of these competencies, making learning more reflective, and support teachers' discourse and inquiry learning practice. This is described by Ennis (1989) as a "mixed" approach to competency integration.

3. There is a lack of comprehensive, scalable assessments for DT and CT. There was a noted absence with the literature of published assessments of DT and CT. This clearly reflects the relative recency of these terms, and their lack of wide adoption as core elements in curriculum frameworks. But it also reflects the challenge of assessing open-ended problems, or substantive multi-disciplinary projects. Such activities are typically assessed by teachers on an ad-hoc basis, and not through any formalized items or model. Typically, a rubric would be developed by the teacher to score elements of the targeted construct. Effective assessments in a project-based curriculum are also typically *formative* in nature, providing teachers with a source of insight into students' thinking that can help shape subsequent instruction. Such assessments and rubrics are difficult to generalize.

(c) Learning Contexts and Environments

The third area of inquiry for the literature review was concerned with learning contexts and environments. Two main findings are as follows:

1. DT and CT can be applied flexibly to support learning that spans formal and informal contexts, and across subject domains. Much of the research concerning DT and CT has been conducted within informal settings like museums or after school programs. Still, the authors universally recognize the relevance of their work to formal contexts in K-16 education. To some degree, informal settings, such as an after-school robotics program, allow for greater depth of inquiry and higher levels of creativity and collaboration. Thus, while researchers study the development of DT and CT in these contexts, they are eager to see such forms of learning within then more formal curriculum. With regard to the design of learning environments and contexts, the literature suggests that DT and CT, with all their respective dimensions, are best supported in less traditional classroom designs in which students, teachers and furniture can be move about in support of spontaneous collaboration, and extemporaneous, self-directed inquiry. Makerspaces are an interesting example of a less formal kind of space that can be used within a formal course or major project. While there are some forms of design-oriented activities that use such spaces, DT does not require such activities, and can occur within more conventional settings and materials (e.g., paper-based problems with an open-ended or creative aspect).

2. A wide range of platforms can support students in engaging in CT, while far fewer are explicitly dedicated to DT. Perhaps because of their intrinsic technological nature, many software environments are recognized as powerful contexts for engaging CT. These include spreadsheets, Block-based programming environments such as or Android App Inventor (Morelli et al., 2011), or hybrid programming environments like Game Maker (Jenson & Droumeva, 2016). For both CT and DT, Robotics construction kits are popular (Sullivan & Heffernan, 2016), as are simulations or microworlds like Lattice Land (Pei, Weintrop & Wilensky, 2018) or Paper Circuit (Lee & Recker, 2018) that allow learners to explore disciplinary ideas through computational manipulations Non-computer-based activities also can effectively engage students in CT, allowing the modeling of problems and formulation of solutions before jumping into computation (Lee, Mauriello, Ahn, & Bederson, 2014). Because DT is largely seen as a cross-disciplinary approach to problem-solving, its application is seen across many domains and settings, including geography and engineering classrooms (English et al., 2012), game design classes (Marchetti & Valentine, 2015), arts (Watson, 2015), makerspaces (Sheridan et al., 2014, Blikstein et al., 2017), and after-school programs and libraries (Scheer et al., 2012; Coleman, 2016).

3. In some cases, DT is integrated deliberately across the entire school curriculum. While there are relatively few platforms that are expressly designed for design thinking, there are some that appear to be well suited as contexts for DT. For example, FUSE Studio (Jona, Penny & Stevens, 2015), has students engage in design activities in order to "level-up" to increasingly more complex design challenges. MIT's App Inventor focuses specifically on DT, aiming to support students in developing mobile applications that can have a direct impact in students' lives and communities (Tissenbaum et al., 2019).

(d) Teaching with DT and CT

The fourth area of inquiry for the literature review was concerned with learning contexts and environments. Three main findings are as follows, including some supportive evidence drawn from Section 1.

1. Teachers' pre-existing ideas about DT and CT may inhibit their integration of related new forms of practice and classroom discourse. Teaching and learning with DT and CT will entail some characteristic elements. Students are largely in charge of their own learning activities, constrained by curriculum guidelines, and often blending school, home and field contexts. The teacher will be engaged most often with individuals and small groups, periodically calling the class together for short periods of instruction or discussion. Many scholars have interpreted this challenge as one of shifting patterns of discourse (e.g., Grossman, 2018; Resnick, et al., 2018; Goldman, 2018). Rather than explaining and convincing and conveying information, teachers must support students in developing a sense of autonomous inquiry, practicing relevant subskills, and collaborating with peers. This places teachers in a role of mentorship, and results in discourse patterns such as "accountable talk" (Resnick et al, 2018) or "responsive teaching" (Robertson et al., 2015). With regard to teacher knowledge and professional development, research suggests that teachers may have limited understandings of DT and CT, or about competency-centred instruction more generally, and that those ideas could actually inhibit their adoption of new forms of practice and classroom discourse.

2. Teacher professional development often employs DT and CT activities, so that teachers learn through doing those activities themselves. In general, it is not well understood how teachers come to adopt new ideas and practices. Although not much work has addressed teachers' learning of DT and CT, some published studies suggest that teacher professional development can succeed by actually engaging teachers in learning through DT and CT activities, so that they can experience firsthand how DT and CT engage thinking and reasoning within their domain.

3. Teacher support materials should make explicit connections to DT and CT and show how those forms of thinking (1) are engaged by curriculum, (2) help students develop deep understandings, and (3) require new forms of classroom practice and discourse. Effective teaching with DT requires teachers to have a strong understanding of the Design Cycle and how it integrates into their classroom practices (Glen et al., 2015). Teachers should also be comfortable with practices that support students through the design process such as argumentation (Mathis et al., 2017), design sketching (Kelly, 2017), and in some cases the use of tools for 3D design and fabrication, storyboarding, and graphic design (O'Byrne et al., 2018; Nottingham, 2017). Effective teaching of CT requires teachers to have knowledge about CT concepts and practices, knowledge about learners' difficulties with CT, knowledge of pedagogical strategies specific to teaching CT, and knowledge of affordances and limitations of supporting technologies, and knowledge of the global, local, and classroom context (Angeli et al., 2016). Not only must teachers have knowledge about DT and CT concepts and practices, they must also know about learners' difficulties with DT and CT, as well as some knowledge of pedagogical strategies, the strengths and limitations of supporting technologies, and a wide range of curriculum connections. Finally, in addition to these forms of knowledge and skills, teachers' attitudes about such instruction were also found to be of great importance to their successful planning and implementation of competency-centred approaches. Thus, teacher support materials should make explicit connections to the constructs of DT and CT, and show how (1) those forms of thinking are engaged by curriculum; (2) how such curriculum helps students develop deep understandings in the discipline, and (3) what new forms of classroom practice and discourse help ensure effective learning and teaching with these methods.

3.2 Curriculum audit

This section reports findings related to the integration of DT and CT within the DP, MYP and PYP. Due to scope, this research did not include auditing IB's Career Programme (CP) programme. However, many of the recommendations and insights gained from the DP will be relevant for the CP, and the DP could benefit from strengthening links to the CP with regards to these competencies. Sections of course guides, scope and sequence documents, assessments and TSM were coded according to the working definitions for the Presence, Guidance sufficiency, and Opportunities for linkage. Section 2 presents programme-level summaries, referring to Appendix C where more detailed discussion is provided for each course, including specific coding outcomes and "Opportunities and Considerations" for deeper integration of CT and DT. Three main findings are articulated below:

1. Current IB programmes emphasize real-world problems and many courses include a focus on open-ended problems, creativity and design. All three IB programmes (DP, MYP, and PYP) make a concerted effort to connect student learning to real world problems, creative thinking, and multidisciplinary approaches. Often, these goals are described at a high level within the front matter of the Guide or TSM, leaving the details of how these goals are achieved as a matter for teachers to address on a case-by case basis. This is clearly a solid and necessary approach for any programme that hopes to serve such a breadth and diversity of locations and constituencies. Thus, we understand the need for some leeway in how teachers address the learning goals, and also that teachers couldn't really succeed in adopting courses where every detail of the curriculum was fully specified. There is clearly a balancing act between giving guidance and allowing teachers to develop an approach that is tailored to their specific context.

2. Some dimension of DT and CT like Collaboration and iterative improvement are recognized explicitly as value, especially in the MYP, but are not often addressed with any explicit guidance, assessments or TSM. In general, there was low *presence*, particularly in the TSM and assessments the authors looked at in the audit. Often the guides mention the importance of inquiry, collaboration and creativity, but there is little specific *guidance* or rich examples to show how such dimensions could be added to the courses specifically for DT and CT. There was ample *opportunity* coded across all course materials, suggesting there were many places where guidance about DT and CT could be added.

3. Many dimensions of DT and CT were found within the course materials, but these were likely present because of an overarching commitment to inquiry and project-based learning, which share some of the same dimensions (e.g., creativity, or real-world problems). While creativity and problem solving were regularly highlighted, other dimensions of DT (e.g., iterative testing and revision) and CT (e.g., algorithms and problem decomposition) were much less prominent, presumably because they are more specific to design and computation. Indeed, there was little specific mention of either DT or CT by name, which may be due to their relative recency as explicit constructs. Moreover, much of the *presence* of DT or CT could be construed as incidental in nature – i.e., not deliberately concerned with including those competencies, but simply coded because of the presence of underlying dimensions like collaboration or problem solving. Thus, an important distinction should be made between (1) inadvertently including some dimensions of DT and CT, and thereby achieving some level of integration, and (2) intentionally targeting these competencies and ensuring that students are engaged in those underlying elements in order to achieve them.

3.3 Survey of teachers

This aspect of the work supported research of how well teachers understand DT and CT, their approaches to integrating those competencies, and the challenges they perceive in doing so. Findings are presented for three main questions regarding (a) Teachers' understandings of DT and CT, (b) their approaches to integrating DT and CT, and (c) the challenges or obstacles they identify within their respective programmes.

(a) Teachers' understandings of DT and CT

1. Teachers from all three programmes report a high level of familiarity with and understanding of DT and CT, and how it can fit within their courses. Teachers broadly reported that they are aware of and understand DT and CT, as critical 21st century competencies. They reported confidence that they are effectively integrating these constructs into their courses. Thus, despite the need for improved guidance and support, there appears to be a consensus amongst teachers that DT and CT are priorities, with some shared understandings about how they can be targeted by instruction.

2. Project-based work is commonly cited as a strategy, where students must engage in creative problem solving. There is a common recognition of the value of open-ended projects in which students must creatively apply the ideas and topics from the course. This strategy is prominent within PYP and MYP, but also appears frequently in comments from DP teachers. Many teachers recognized the value of collaboration for learning, as well as multi-disciplinary projects. Teachers understand how the use of data, graphing and modeling techniques can support development of CT. In PYP, there was a clear consensus that engaging in number play and reasoning about shapes would promote CT. Thus, teachers from across the IB have clearly understood the importance of project-based work, design, and transdisciplinary learning. These teachers also clearly feel that, by engaging in such forms of inquiry, students will develop deeper understandings of concepts and practices within their course topic.

3. Some teachers expressed limited understandings or lack of confidence in how to integrate DT and CT. Many teachers across the programmes expressed a need for additional guidance, case studies, and other forms of teacher professional development. There were other teachers who expressed reservations, or a lack of confidence in how to integrate DT and CT. This suggests that teachers are aware of the challenging nature of such instruction (i.e., open-ended problems using collaboration and creativity) and are willing to grow professionally, with support. Finally, some teachers simply made no contribution to these survey items, making it difficult to claim anything about their understandings and practices. In general, IB teachers would require further guidance in order to achieve a comprehensive understanding and treatment of DT and CT.

(b) Approaches to integrating DT and CT

There were many approaches that occurred in common across all three programs (e.g., the use of open-ended problems), and some that were specific to a program (e.g., play-based learning, for the PYP). Some approaches to including DT were also commonly used for CT. Sections below present each program in terms of the key strategies used by teachers.

1. DP teachers shared a range of interesting ideas and approaches. Instructors offered fewer specific illustrations and activities for CT than they did for DT, with many appealing to the more general computational nature of problem solving. Some Computer Science teachers felt that CT was addressed intrinsically through their very discipline, without need of any further consideration. Other teachers did not see elements of CT within their teaching - perhaps because they were fixed on the necessity to include computers. Design technology teachers appeared to make heavy use of computational projects (i.e., as part of design assignments) While these ideas varied expectedly across the course topics, there were six common strategies identified by DP teachers: (1) the use of open ended and student-centered problems; (2) inclusion of technology-based activities; (3) use of data management and computation in projects and problem solving; (4) scientific method and problem solving; (5) emphasizing collaboration, and (6) Multidisciplinary partnerships with DP Design.

2. MYP teachers again recounted a range of interesting ideas and approaches, which were similar to those expressed by DP teachers. Teachers' strategies varied expectedly across the course topics (e.g., Design teachers exhibited more focused observations about DT than did social studies teachers), and some were more prominent in responses about CT than DT. But many strategies were articulated commonly for DT and CT, resulting in the following set of common strategies: (1) the use of authentic, open-ended problems; (2) the use of iterative cycles of revision; (3) the use of collaborative projects, (4) supporting creativity, (5) connecting design and computation; (6) integrating programmable hardware technologies; (7) the use of programming environments; (8) working with data.

3.PYP teachers showed a remarkable sensitivity to the importance of DT and CT, and strategic insight about how to target those competencies. While one might expect primary teachers to be less familiar with DT and CT, there was a general appreciation expressed by teachers of their importance – even for children of a young age. Many teachers did appear to feel that CT would be engaged through the use of technology, although some did cite activities that are not performed on computers. Teachers of the younger students (age 3-6 years) suggested the following strategies. (1) play and creativity, (2) open ended problems, and (3) collaboration or group work; (4) finding patterns, (5) breaking problems into smaller parts, (6) the use of puzzles and problems, (7) adding technology. Teachers of older students (age 7-12 years) included many of those same strategies, as well as: (8) computer games, (9) use of concept maps and flow charts, (10) robotics, and computer programming; (11) integration of topics across disciplines, and (12) student-selected problems.

(c) Challenges identified by IB teachers

1. DP teachers feel there is too much required content and not enough curriculum time, for the introduction of project-based approaches, and/or open-ended problems. In the DP, teachers often cited issues with "*too much content*" to cover, and a corresponding challenge of "*not enough curriculum time*". This suggests that they are aware of the value of open-ended problems and project-based learning, but do not feel that it is possible to employ such time intensive methods (i.e., the classic tension of "depth vs. breadth"). The DP is challenged to allow for deep, project-based learning, which would confront the strong emphasis placed by the DP on content-heavy assessments. In the MYP, fewer teachers cited the heavy content requirements. However, there were some who argued they needed more time for projects (e.g., in Math and Science), suggesting the need for a program-wide emphasis on problem solving, creativity, and data-driven reasoning. In the PYP, some teachers expressed the need for more curricular time devoted to integration of DT and CT, suggesting there is sometimes a perception of constraint or limitation imposed by their school's inquiry plans.

2. Teachers need more guidance in designing and enacting activities that use DT and CT, as well as the need for assessments. Many DP teachers cited the lack of strong examples of "*how to do this,*" and the need for professional development. Some asked how DT and CT should be assessed and asked for TSMs that illustrated such curriculum and assessment. It was felt that some required assessments would provide a "target" or reference that would guide their design of activities. MYP teachers felt that, while there is a stated value of project-based learning and open-ended problems, there is a lack of guidance about what those look like for specific courses. PYP teachers often cited the need for more support in adapting their inquiries to include DT and CT integration. Some felt that their school does not prioritize such learning, while others cited a lack of resources such as worksheets, guides and starter activities. Some teachers described a need for more clarity in the TSM about how to address these constructs - especially CT.

3. Some teachers, especially in the PYP, feel their students are not ready for such forms of curriculum. either because of perceived behavioural issues, or because they believed these forms of learning are developmentally inappropriate.

4. Considerations for IB programmes

In response to the challenges identified in the previous section, several considerations were articulated, both at a general (cross programme) and specific (within programme) level.

(a) Considerations across all programmes

1. Improve the guides and TSM, making explicit reference to DT and CT as a basis for powerful teaching and learning, and as important 21st century competencies. In the DP and MYP, new versions of the Guides and TSM could make explicit connections to DT and CT, and offer some insight about the kinds of activities that would engage DT and CT. The guides could also describe the relevance of DT and CT to the instructional domain. Corresponding sections could be added to the TSM to offer insight into supportive teaching and assessment practices.

2. Make the assessment of DT and CT explicit, so that they will be taken seriously (by students and teachers). By including explicit assessments (and corresponding TSM), a clear message will be sent about the importance of these constructs within the course. Teachers will be able to see what is expected of students, which can greatly support their design of curriculum. This will also serve to introduce the terms DT and CT into the wider discourse of the IB, which can only help to establish their value. For example, it will be very helpful to create TSMs with explicit guidance and rich examples for teachers, and to make DT and CT explicit within those examples.

3. Adopt programme-wide emphasis on interdisciplinary projects, and revisit breadth of content.

By clarifying the goals of "depth over breadth", the IB can respond to the issue where teachers cannot spend enough time on any topic to actually engage DT or CT. There is already a substantial commitment to projects in all programmes, but not as a primary means of learning content. Clearly this will be more challenging for the DP, in which there are substantial content expectations. But this could entail the removal of some content from each course, to support a more substantive inquiry project. Interdisciplinary collaborations could be supported amongst teachers to allow application of ideas from one course within designs or projects from another. Finally, there are some clear overlaps or connections between DT and CT that make the two forms of thinking well suited for reinforcing one another within the same inquiry project. Collaboration and creativity are not explicit elements of CT, for example, but they could certainly promote problem formulation, decomposition and representation, which are central to CT.

4*. **Support the exchange of programs of inquiry and lesson designs amongst IB teachers.*** One compelling source of insight and guidance for teachers is the exposure to other teachers' successful designs. In the PYP, this would entail the exchange of programmes of inquiry that had been evaluated as particularly effective in engaging DT and/or CT. In other programmes it would amount to the exchange of lesson plans and assessments. Any such object of exchange would need to include pedagogical notes relating to "how to teach this effectively, and how students will learn". Establishing a more dynamic community of exchange amongst teachers from specific programmes or courses would be an excellent means of engaging teachers in reflection and design thinking of their own.

5. Create programme-level plans for teacher professional development that can support schools in helping teachers become more knowledgeable and reflective in their practice. Teachers do not readily shift their instructional practices, even when provided with adequate TSM. There will need to be further professional development around new approaches to competency-centred curriculum and assessments. These could include the creation of online micro-credentials for IB teachers, leveraging existing MOOCS that address teachers' integration of inquiry and technology, or active learning design, as well as the creation of new professional development courses. Programmes could offer supports and guidance for teacher professional development workshops, which schools could customize and implement.

6. Consider design and computation within the landscape of professional practice within the relevant disciplines (e.g., mathematics, chemistry, engineering). Teachers and IB Programme development who work on course designs and frameworks could identify where design is happening and how computation, technology and media are playing a role within the field. This could add a level of personal and social relevancy of the course, as well as vital context, meaning and purpose for students. Future versions of the course guide could provide such a context for the topic of study, promoting interdisciplinarity and giving a sense of direction to instructors and programme coordinators. The Teacher Support Materials could then provide guidance about how to make such career connections, foster interdisciplinarity, and support a competency-centred approach.

(b) Programme specific considerations

For the DP, a specific consideration would be to first engage in some re-design of curriculum expectations, reducing the amount of core content, and adding an emphasis on multidisciplinary projects. Strengthening interdisciplinary connections between computer science, mathematics, and sciences could be one strategy (e.g., creating a multidisciplinary project requirement). For this age group, career identity development is vital, and the DP might consider working with the IB CP programme to strengthen links to the CP Core, such as; (1) incorporating aspects of its reflective projects with a career focus[1], (2) including critical thinking, design, collaboration and technology elements within courses, and (3) focusing on specific skills (i.e. technology, communication or design) as learning goals. To sufficiently engage DT and CT, the DP would need to add emphasis

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[1] IB's Career Programme Core requires students to do a reflective project related to their Career-related studies, they also engage in a course on skills development in the workplace which is transferable to a range of situations.

within the course guides, create TSM that provided course-specific examples, and create assessments that explicitly targeted these competencies, such that students and teachers would acknowledge their centrality. Finding a way to infuse more space in the curriculum for project-based learning approaches, such as in the internal assessment models of DP courses, could be another strategy for the IB to consider.

For the MYP, one specific consideration would be the explicit integration of DT/CT into MYP projects key and related concepts as reflected in the unit planning process, referring to the dimensions of our working definitions. This could entail the production of clear examples and resources. It will be important to consider the learning progressions from PYP throughout the MYP: where will students be starting out, and what are the specific goals, with regard to DT and CT? Most important would be to add a clear emphasis on DT and CT at the programme level (i.e., not just in the Design course), and include dedicated TSMs. Supporting the exchange of lesson and assessment designs amongst MYP teachers across the programme could also provide a powerful source of content and help to disseminate effective designs.

For the PYP, which seems to be fairly well set within a competency-centred framework, greater emphasis could be placed on students' learning progressions, and how these can be supported in the programmes of inquiry: *Where do students start, in relation to problem-centred, creative and collaborative approaches, and how can we support their development?* IB could provide more structured help to teachers, concerning the design of developmentally appropriate activities. Specific guidance could be offered, around DT and CT, to help teachers understand how these competencies will be impacted by a variety of approaches. More effort could also address the progression of DT and CT throughout the programme, including a clear narrative about how design and computation are things that PYP students learn about, and how these will be critical for success in the MYP and beyond.

Section 1

Literature Review

Section 1: Literature Review

This section reports the results of our literature review, which address five distinct topics or themes: (1) definitions of CT and DT, including working definitions that could be useful for IB teachers and IB Programme development; (2) curriculum integration and student learning progressions for CT and DT, (3) assessment of CT and DT, (4) learning contexts and environments; and (5) teacher practice and professional development. For each of these topic areas, we provide a literature review and discussion, followed by a set of "key papers" that can guide further reading.

Methodology: How this literature review was conducted

We conducted a search of research papers published since 2006 in major educational research databases including ERIC, PsycINFO, and JSTOR and the Google Scholar search engine. For the research databases, we conducted the search of peer-reviewed publications written in English using the keywords "computational thinking" and 'design thinking' in the document title or abstract. For Google Scholar, we conducted the searches using the same keywords and selected the articles that have been cited at least 50 times by the end of June, 2018 for both CT & DT. These searches generated 189 unique relevant papers for CT and 201 unique relevant papers for DT. We then further applied a set of criteria to select the essential and highly informative papers for this review:

1. If CT/DT were the phenomenon of interest or primary learning objective;
2. If the studies or perspectives offered unique, generalizable insights on the conceptualization, operationalization, assessment, and teaching of CT/DT;
3. If the studies or perspectives generated actionable knowledge for classroom practices.

Based on these criteria, our review focused on 113 papers for DT and 100 papers for CT, with 28 papers that were common to both. We then developed a set of themes, presented in subsections below, to capture the important dimensions of DT and CT: (1) The integration of DT and CT within curriculum, including nascent models of student learning progressions; (2) Assessment of DT and CT; (3) Learning contexts and environments; (4) Teacher practice and professional development.

In the sections below, we systematically address each of these themes, synthesizing the major findings. At the beginning of each theme, we provide a set of key take-aways salient to IB programme development and IB schools, as well as a set of "Key papers" that were important to our review. These papers are also included in a longer annotated bibliography provided in Appendix A. To begin, we focus on a review of DT and CT definitions, in order to establish working definitions that guided the curriculum audit and the design of the survey of IB teachers to investigate subsequent research questions.

Theme 1. What are the definitions of CT and DT?

Key Take-aways

- DT and CT are competencies that underlie successful engagement in activities such as product design or computer programming. They can be articulated in terms of associated skills or dimensions.
- There are many definitions of CT and DT, which are often applied in the context of workplace learning.
- Definitions of DT and CT emphasize the importance of open-ended problems that students must solve creatively through design and computation, and collaboration.
- Many activities and resources that include DT also include CT (and vice versa) such that the two can be considered as mutually reinforcing.
- CT and DT both are concerned with solving open ended problems or creating solutions within inquiry learning.

We recognize the ambiguity of terminology like DT and CT, even amongst researchers who originated the terms and are now exploring these forms of thinking. There are a wide range of contexts in which design and computational thinking can occur (e.g., formal and informal learning, workplace, online and face to face environments), as well as different age levels and sophistication of activities (e.g., elementary students' play-based learning vs. undergraduate engineering design or software development). Because researchers and practitioners use the terms DT and CT in reference to such a wide range of contexts, participants and activities, the definitions have become nebulous. Some definitions are highly nuanced, to guide the investigation of particular forms of activity, or to understand the intersection within specific disciplines. Other definitions are more sweeping, in an attempt to characterize the general tenor of knowledge, learning and reasoning entailed. We reviewed papers from a range of perspectives, including theoretical descriptions of students' internal thinking processes (Ho 2001), empirical studies of particular teaching approaches (Noweski et al., 2012; Gadanidis et al., 2017), pedagogical models like the design cycle (Bequette & Bequette, 2012; Dorst, 2015; IDEO, 2013), or sets of subskills to be targeted by instruction (Crismond & Adams 2012; CSTA, 2011). As it is difficult to find a single authoritative account, our review aims to provide a synthesis of the articles, and a working definition that is well suited to the needs of the IB community. These definitions will also guide our audit of existing IB curriculum in the subsequent sections of this report.

To begin, we draw an important distinction between *kinds of thinking* (e.g., DT and CT) and the *activities they underlie* (e.g., design and computer programming). The notion of computational thinking arose because scholars recognized a basic set of sub-skills that was common to many forms of computer programming and technological problem solving (Wing, 2006; Barr & Stephenson, 2011). Likewise, as design became increasingly commonplace (e.g., in designing Web sites or games), it became evident that those who succeeded widely in such activities possessed a certain core set of skills or heuristics (Wrigley & Straker, 2017). Hence, DT and CT were invented in reference to particular forms of cognition, patterns of reasoning, problem solving and inquiry that happen within the context of design-oriented and computationally oriented activities. By understanding the underlying cognitive and social processes, educators can inform the development of pedagogical approaches, activities and materials that foster such thinking.

In this report, we refer to DT and CT as "competencies", because they are seen as critical to the performance of certain activities, and often include an aspect of disposition or frame of mind, making them similar to other competencies, like critical thinking or problem solving (Noweski et al., 2012). To possess such a competency implies certain subskills, such as decomposing problems, forming algorithms, testing prototypes. It also entails certain dispositions like creativity and collaboration. It must also be noted that some of these same skills and dispositions are required for related forms of activity like inquiry or project-based learning. And indeed, inquiry and problem-based learning can both be said to engage DT and CT, to some degree. Finally, we define DT and CT as distinct constructs below, recognizing that they often co-occur within curriculum, that they share some underlying elements (e.g., abstraction, modeling, or iteration), and that there are important theoretical ideas related to their intersection.

Definition of Design Thinking as competence

Buchanan (1992) was one of the first to articulate design thinking as a combining of empathy, creativity, and rationality to analyze and find solutions to a problem in a particular context. Within K-12 education, design thinking is recognized as a form of cognitive engagement that supports creative problem solving and collaboration. Carroll et al. (2010) articulated a set of design thinking principles that include engaging students in empathy, collaboration and facilitation, human-centeredness, and creativity through iterative prototyping and testing. These principles have been shown to support students to develop their creative confidence and have help prepare students for the challenges of the 21st century workplace (Noel & Liub, 2017; Noweski et al., 2012). Some researchers have included a focus on aesthetics within their definitions (Bequette & Bequette, 2012), encompassing visual elements such as how the final product looks, and how information is conveyed to users. Aesthetics can help students consider how their solution balances function and form, and how it reflects their attitudes, customs, and beliefs (Vande Zande, 2010). Aesthetics can also play a role in the design of the solution, demanding careful attention to the use of sketches, renderings, and engineering drawings (Bequette & Bequette, 2012; Dym et al., 2005). The value of aesthetics within design thinking raises unique opportunities for interdisciplinary projects, such as integrated STEAM (Science, Technology, Engineering, Arts, and Math) activities (NRC, 2011).

In educational practice, the engagement of DT often necessitates students solve open ended or unstructured problems (Buchanan, 1992) that draw upon pedagogies from problem-based learning (PBL – see Hmelo-Silver, 2004). In problem-based learning, students collaborate to solve complex problems that do not have a single correct answer, leading to a variety of design solutions that can inspire further whole-class discussions. PBL is also seen as an effective pedagogical approach for interdisciplinary learning, such as STEM or STEAM. Activities that engage students in DT often include iterative cycles (i.e., of design, testing, evaluation and redesign), require students to tolerate ambiguity, ask systematic questions, keep the big picture in mind, make decisions, handle uncertainty, think and communicate in the languages of design (Dym et al., 2005). Noweski et al (2012) emphasize the collaborative nature of DT, " Challenges are tackled in interdisciplinary teams with a clear focus. The teams should ideally work together in a flexible working environment and in creative freedom, while at the same time being guided systematically through an iterative process." (p. 79)

The Design Cycle

A unique feature of many design-oriented curricula is the design cycle: a formal model of the steps taken in the process of design. The design cycle generally includes steps like considering the problem and challenges that need to be solved, research, the benefits and drawbacks ideas, coming up with design options, developing prototypes, and then testing and evaluating their usefulness (Bequette & Bequette, 2012; Dorst, 2015; IDEO, 2013). Bequette & Bequette (2012) define the design cycle as "the steps that consider the problem and challenges that need to be solved, the benefits and drawbacks of different ideas and material choices, coming up with one or several design options, conveying raw ideas as prototypes, and then testing and evaluating their usefulness" (p. 44). This design cycle is central to the work of professional designers and engineers, as popularized by Stanford "d.School" model:

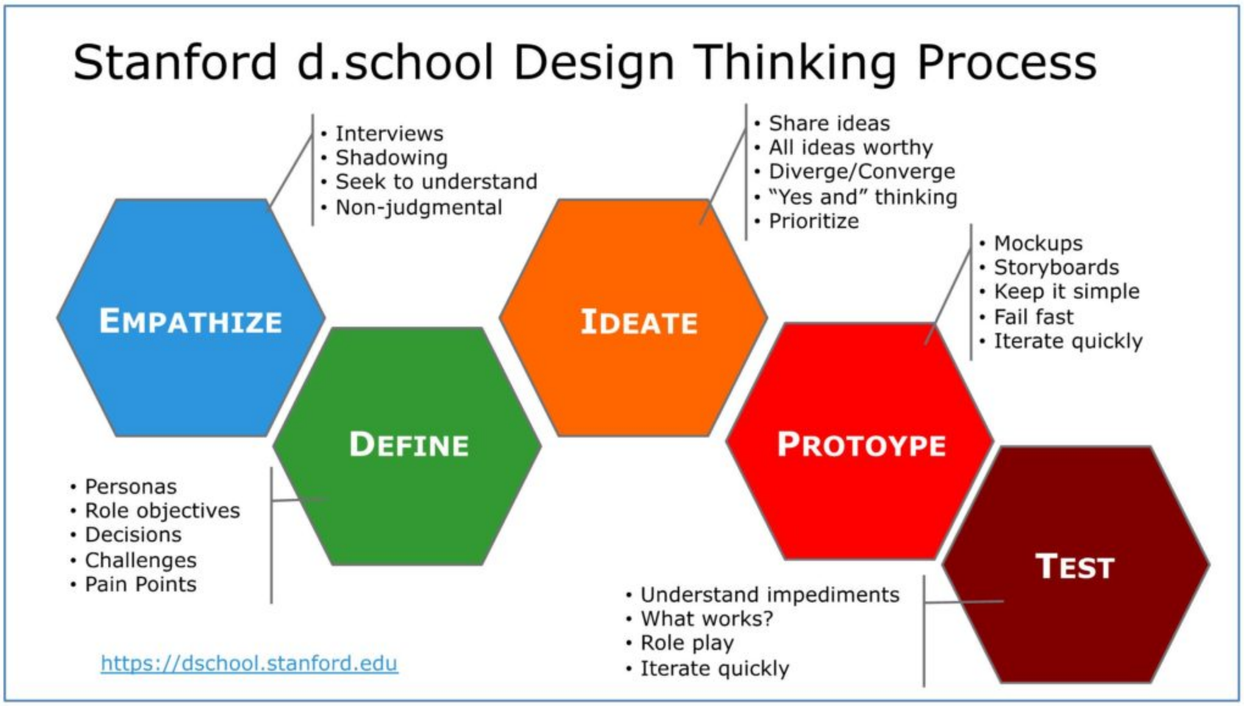


Figure 1. Stanford d.school Design Thinking Process.

The MYP has defined a Design Cycle that includes four primary activities: (A) Inquiring and analyzing; (B) Developing ideas; (C) Creating the solution; (D) Evaluating, which occur with a cycle. The MYP design guide includes a learning progression that can be used to guide curriculum and assessments, that is linked to the cycle itself. This will be discussed further in sections below.

Working Definition of DT

For purposes of the present work, we have developed the following operational definition, which blends the ideas of Noweski et al. (2012) and Bequette & Bequette (2012):

Design thinking is a competency that underlies developing creative solutions to open-ended, unstructured problems, often in collaboration amongst peers. Design thinking requires a disposition of creativity, empathy, and communication in the language of design. Solutions progress through iterative cycles of design, building, testing, and redesign. Design thinking includes sub-skills of (a) inquiring and analyzing, (b) developing ideas, (c) creating designs, (d) evaluating designs, and (e) iterating on designs. Five characteristics of activities that engage DT are as follows:

- **OPEN-ENDED, ACCESSIBLE PROBLEMS.** Students must perceive a broad space of possible solutions to personally relevant problems.
- **COLLABORATION IS EMPHASIZED.** Students are encouraged to work with a partner or small team in the design process.
- **CREATIVE PROCESSES ARE EMPHASIZED.** Students understand that creative thinking is a valued, and even assessed dimension of the assignment, and may even be necessary to find a solution.
- **AN ITERATIVE DESIGN CYCLE IS EMPHASIZED.** Students understand that they must evaluate the success of their designs to inform design improvements in an iterative cycle.
- **DT IS EXPLICITLY EVALUATED.** Students understand that design thinking is a valued part of the assignment and will be evaluated as an element of the assessment.

CT CONCEPTS
(CSTA & ISTE)

1. Data Collection
2. Data Analysis
3. Data Representation
4. Problem Decomposition
5. Abstraction
6. Algorithms & Procedures
7. Automation
8. Parallelization
9. Simulation

Definition of Computational Thinking as competence

The origin of computational thinking is somewhat controversial in the literature and in academic discussions. Wing (2006) defined computational thinking (CT) as "solving problems, designing systems, and understanding human behavior, by drawing on the concepts fundamental to computer science" (p.33). Her interest and rationale for this definition was to expand understanding of how people learn, think and reason with and about computing. Wing challenged educators with the assertion that CT is a "fundamental skill...every human being must know to function in modern society" (p. 35). In support of this perspective, Denning (2009) pointed out that even social scientists increasingly rely on computational models to conduct their research (e.g., predicting urban growth, describing social network structure and dynamics), suggesting that computational thinking doesn't just apply to computer programming or computer science. Indeed, phenomena from nearly every domain can be understood through the lens of computational modeling (e.g., timing of traffic lights, accounting for biochemical processes, or planning internet advertising). Thus, CT is not unique to computing, and is a way of thinking that supports the general understanding and controlling of information processes.

Scholars have provided a variety of perspectives and definitions of CT, emphasizing different aspects of the notion, and different domains in which CT would occur. Isbell et al. (2009) conceptualized computing (and computational thinking) as a modeling activity involving the mapping of a phenomenon with a computing machine manipulated through a language. Barr and Stephenson (2011), in applying CT at the K-12 level, stressed the transferability of CT beyond the computing field. Berland and Wilensky (2015) described CT as a perspective that allows one to see computing and applications of computational thinking in any context.

Most relevant to this report are papers that focus on the specific sub-skills associated with CT in K-12 schooling. The Computer Science Teachers Associations (CSTA) and the International Society for Technology in Education (ISTE) (Barr & Stephenson, 2011) formed a task force on CT teaching and learning. They identified nine CT concepts and capabilities including data collection, data analysis, data representation, problem decomposition, abstraction, algorithms & procedures, automation, parallelization, and simulation. They also provided examples of CT-based activities in computer science, math, science, social studies, and language arts classes. Csizmadia et al. (2015) identified six concepts including logical reasoning, abstraction, evaluation, algorithmic thinking, decomposition, and generalisation, and evaluation as well as techniques, or "computational doing", including reflecting, coding, designing, analyzing, and applying.

We created the following diagram based on a synthesis of models and frameworks of CT that appeared in the educational research literature from 2006 to 2018. A content analysis of 12 major publications resulted in 52 terms that were then categorized as objects, attributes, or actions,

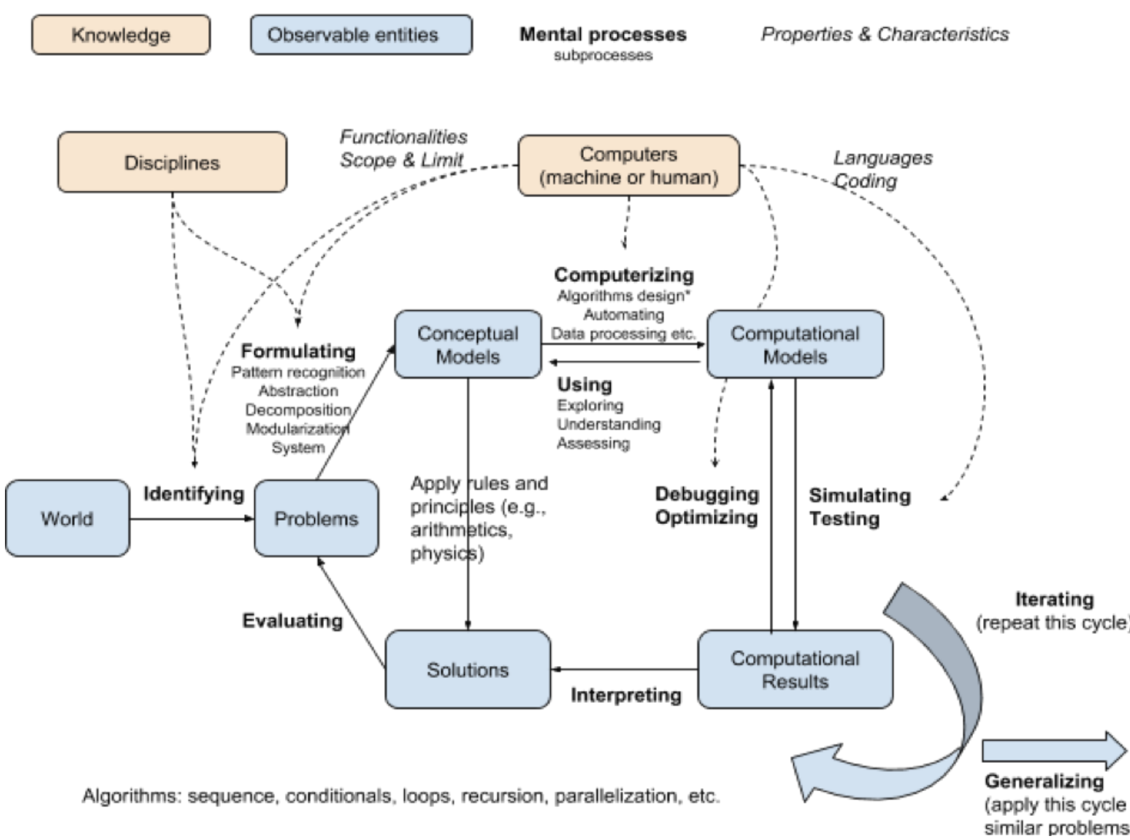


Figure 2. Synthesis diagram of computational thinking processes.

While Figure 2 offers a complete description of CT processes, accounting for the wealth of content in models from across the literature, this description is too abstract to be directly useful for K-12 educators. We offer it as a reference, to exhibit the movement between conceptual and computational models, outcomes, evaluations and iterative refinements that characterizes computational thinking in the most general or universal account. For purposes of this report, we seek a working definition that is cast at a more concrete level, and emphasizes the specific sub-skills that would constitute presence or engagement of CT in a curriculum design or classroom enactment.

Working Definition of CT

Building on the diagram above, the following definition can guide our review of IB curriculum in terms of opportunities for integrating CT, which is seen as a particular form of problem solving and reasoning. In addressing open-ended problems, students rely on CT whenever they formulate the problem in such a way that its solutions can be represented as algorithms that can be worked through either by computers or humans. Complex problems can be decomposed into simpler ones, whose solutions can then be assembled together to solve the original problem. Such algorithmic solutions typically require the use of abstract representations of the problem (e.g., using models, equations and simulations) as well as the organization and analysis of data that is based on those abstractions. Once the algorithms have generated some solution, students continue iteratively to check the outcome (i.e., debugging) and improve their solution. While this process underlies most computer programming, the strategies, patterns, and techniques of computational thinking can be applied to a wider class of problems and areas of daily life (e.g., coordinating a complex schedule or organizing our daily routines to be more efficient).

Referring to the synthesis diagram, we articulate seven fundamental processes that are common within activities that engage computational thinking:

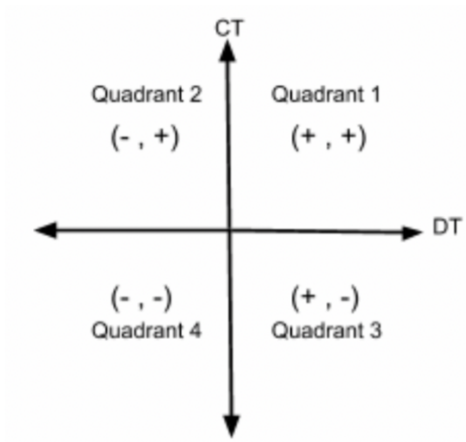
- **FORMULATION.** In order to solve the problem effectively and efficiently, students will formulate the problem in a way that its solutions can be represented as algorithms and executed automatically, either by machine or human.
- **DECOMPOSITION.** If the problem is too complex, students will decompose the complex problem into simpler solvable problems, whose solutions can be executed in parallel or assembled together to solve the original problem.
- **ABSTRACTION.** In order to formulate and decompose problems effectively, students represent the problem through abstractions (e.g., models, simulations) as well as organize and analyze data based on those abstractions.
- **ALGORITHMS.** Using the abstract version of the problem, students will create algorithms to render the solution for the problem.
- **DEBUGGING.** Once a solution is obtained, students need to check and correct any errors in our solution (debugging).
- **ITERATION.** In response to their outcomes, students iteratively improve their solution to achieve greater effectiveness and efficiency.
- **TRANSFER.** Students can apply such strategies, patterns, and techniques to other problems in their schooling or daily lives.

The processes above can be seen as dimensions of our working definition. To the extent that we see evidence of these processes or sub-skills, we can infer that CT is being engaged. While these processes often occur together during computer programming (i.e., according to the synthesis diagram above) they can also occur separately or in any combination. The various definitions described above (e.g., Wing, 2006; Barr & Stephenson, 2011) typically consider CT to occur when any (i.e., not all) of these kinds of thinking and reasoning occur. Thus, if a mathematics class engages students in formulation and decomposition, but students never progress to abstraction and algorithms, we can still argue that some dimensions of CT have been exercised. By examining a curriculum according to the presence of these sub-processes, we can evaluate the presence of CT within the curriculum and identify opportunities for expanding its inclusion.

The relationship between DT and CT

We also recognize intersections between CT and DT — particularly in the curricular context, where activities often leverage both DT and CT for a particular activity (often in STEM topics). For example, the FUSE programme from Northwestern University (Stevens et al., 2016) embeds CT in robot and game design challenges. Energy3D, from the Concord Consortium, aims at teaching engineering design through modeling and simulations that target CT and DT together (Xie, Schimpf, Chao, Nourian & Massicotte, 2018). Similarly, MIT's App Inventor combines CT, DT and specific domain contexts (e.g. engineering or environmental sciences education), to support students in developing solutions to problems in their communities through mobile app development (Tissenbaum, Sherman, Sheldon & Abelson, 2018). These projects all rely on design as a pedagogical frame, with the aim of fostering DT, but also engaging students in CT.

These overlaps are reflected in the dimensions articulated within our working definitions, where there are some common dimensions within the two sets, including a problem-based focus, and some form of evaluation (i.e., debugging, in the case of CT), as well as iterative improvement. Thus, many activities in which CT is engaged will also entail some dimensions of DT, and vice versa. An open question within the research literature on CT is whether an activity must actually include computers or computation in order to qualify as an instance of CT. Many authors feel that simply engaging algorithmic thinking qualifies as engaging CT, while others feel that such thinking must be connected to a technological problem. For the purposes of our curriculum audit, we will rely on the working definition, which allows a simple coding of the dimensions.



Appendix B offers a set of resources that are relevant and accessible for the integration of CT and DT within the various IB programmes. For each of these resources, we evaluate its potential for engaging DT and CT. This coding will allow teachers and IB programme development to evaluate within their contexts those resources for integration in their curriculum designs and frameworks allowing us to discuss resources and approaches that are high in both CT and DT (quadrant 1), high in CT with some limited elements of DT (quadrant 2), or high in DT with some limited aspects of CT (quadrant 3).

Key Reviews Papers

There are a number of recent scholarly reviews of the research in computational and design thinking. Below, we provide a short list of the articles that are accessible appropriate to IB curriculum specialists, programme leaders, practitioners, school leaders or researchers. These are reviews that have been well received in the research community, and could help any reader develop a deeper understanding of DT and CT.

- Grover, S., & Pea, R. (2013). Computational thinking in K-12: A review of the state of the field. Educational Researcher, 42(1), 38-43.
- Lye, S. Y., & Koh, J. H. L. (2014). Review on teaching and learning of computational thinking through programming: What is next for K-12? Computers in Human Behavior, 41,51-61.

- Sullivan, F. R., & Heffernan, J. (2016). Robotic construction kits as computational manipulatives for learning in the STEM disciplines. Journal of Research on Technology in Education, 48(2), 105-128.
- Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017). Demystifying computational thinking. Educational Research Review, 22(November), 142–158.

Theme 2: Curricular integration and student learning progressions

Key Take-aways

- It is productive to think of DT and CT as competencies (ways of knowing and learning) that students acquire and apply during curricular engagement.
- The most effective curriculum design strategies are those that address CT and DT explicitly and employ project-based or design-centred approaches.
- Learning progressions are better defined and articulated for CT than they are for DT.

It is challenging to design K12 curriculum and assessments that foster CT and DT. Clearly, one could anticipate the inclusion of design activities (e.g., design a car or house) or projects that center around computer programming (e.g., robotics). But should those activities be exclusively purposed to learning about design and computing (e.g., students developing a computer programme in a computer programming class) or should they be in service to the broader spectrum of topics and courses (e.g., developing a computer programme as part of an arts or science project)?

Another challenge is concerned with our understandings of how learning progresses in a student's schooling experience. What goals should teachers of primary age students maintain, in anticipation of the middle year curriculum, and so on to high school and beyond? In most topics like mathematics and science, educators have some understanding of the scope and sequence of learning – which topics are appropriate at what ages, and how one topic can support the next. DT and CT are not topics to be instructed, but rather more like competencies to be nurtured. But there still remains the question of how these competencies mature, what forms of activity are appropriate at different age levels, and how such activities support the development of the competencies.

To integrate any form of competences in the area of thinking, reasoning, or social interactions, curriculum designers must create activities and sequences where those targeted forms of thinking and interaction would likely occur. The research literature may reveal specific approaches that succeed in studies, but these must be translated into curriculum design guides and ultimately into specific lessons and assessments. Our goal in this review is to understand what the research literature has to offer, for IB teachers and programme development teams, to guide their integration of DT and CT.

The integration of competencies

Our goal is to understand DT and CT as *competencies* that will serve students in learning across disciplines and throughout their lives. Rather than specific skills or bodies of knowledge to be learned, these are *ways of knowing and learning (such as within IB's Theory of Knowledge Course).* And as such, it is important that teachers see them not as topics to "cover", but rather as *a means of covering other topics*. One might compare DT and CT to other competencies such as inquiry and critical thinking, which are already well-established goals of the IB curriculum. By engaging in inquiry and critical thinking, students are able to build connections among topics, deepening and extending their understandings. Students gain or develop such competencies through engaging in curriculum activities that use inquiry as a way of learning. In the same way, CT and DT can be engaged through the careful design of curriculum that engages their various sub-skills (per the working definitions above).

Curriculum integration can be described in a variety of ways. Ennis (1989) offers one perspective that may be a good fit to the purpose of understanding DT/CT integration. In trying to understand how the competency of *critical thinking* could be incorporated into higher education courses, Ennis articulated 4 possible approaches, shown in Figure 3: (1) the *general approach*, in which critical thinking would be treated explicitly in a general course, with students expected to engage in relevant activities throughout the curriculum; (2) the *infusion approach*, in which critical thinking would be introduced explicitly to students, and then infused into subject matter courses; (3) the *immersion approach,* in which students would be engaged in the relevant forms of thinking by carefully designed activities, and would acquire understanding and expertise without any explicit instruction about them; (4) a *mixed approach* which blends the general with either immersion or infusion methods. (c.f.; Tiruneh, Verburgh & Elen, 2014).

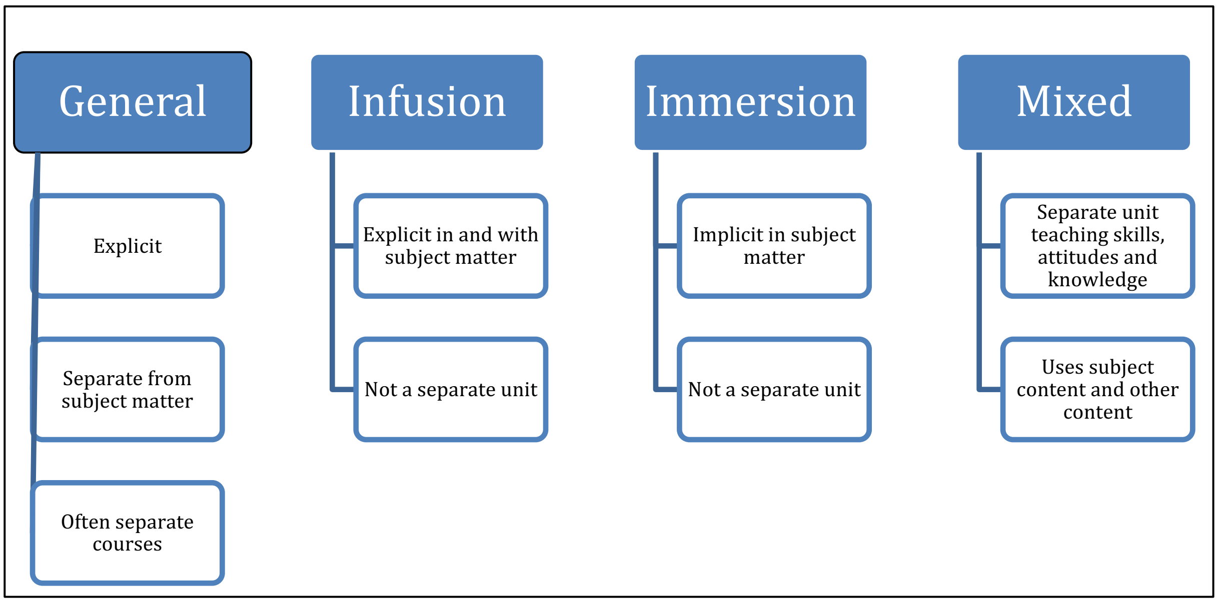


Figure 3. Ennis (1989) Model of Curriculum Integration

For the purposes of this research, we feel that Ennis' (1989) model can be a helpful guide to thinking about the integration of DT and CT within IB curriculum. Rather than interpreting DT and CT as topics that are explicitly addressed within any course, these competencies should be addressed in the *Immersive* or *Infused* form (i.e., sometimes explicit, other times implicit) —occurring throughout the course and across topics. In short, competencies like DT and CT are not a topic to be covered, but are rather pedagogical approaches through which students can learn about topics (and thereby also develop improved competence in them).

One common pedagogical approach to support the integration of DT and CT (i.e., in Ennis' *immersion or infusion* approaches) is that of *project-based learning* - where projects serve to engage students in achieving goals that are authentic and relevant to the students themselves (e.g., Interactive

Journalism, as discussed by Wolz, Stone, Pearson, Pulimood, & Switzer, 2011). As students approach their projects, they identify gaps in knowledge and the needs for new skills and strategies, which lead to motivated, contextualized learning experiences (e.g., Repenning et al., 2015; Vallance & Towndrow, 2016). A specific form of project-based learning called *design-based learning* organizes students' learning experience around a design challenge, which requires a set of domain knowledge and skills as well as CT concepts and techniques to complete (Kolodner et al, 2003; Jun, Han, & Kim, 2017). Another promising pedagogical approach, *Game-based learning,* can engage CT by leveraging game mechanisms such that learners must "program-to-play." This can open up learning pathways and promote affective outcomes, using such devices as puzzles (Snapp & Neumann, 2015), victory points (Kazimoglu, Kiernan, Bacon, & MacKinnon, 2011), and role-playing (Pellas & Peroutseas, 2016).

In most cases, teaching practices employ multiple pedagogical strategies and curricular integration types (i.e. mixed approach of Ennis's 1989 model). For example, the RoboBuilder video game investigated by Weintrop, Holbert, Horn and Wilensky (2016) requires students to design in-game artifacts to play the game. Another combination is to have students design games for others to play (e.g., Repenning et al., 2015; Wu, 2018; Garneli & Chorianopoulos, 2018).

Student learning progressions for DT and CT

To create curricula that fosters students' development of DT and CT, we must have a clear understanding of the *learning progression* within those forms of thinking. Black, Wilson & Yao (2011) described the notion of a "Learning progression" to discuss how students' ideas develop over time within the context of curriculum, pedagogy and assessment. Krajcik (2011) describes this as a "growth perspective" and insists that it is an uncommon way of thinking about curriculum. Scholars have introduced frameworks that define such progressions for specific topics in K-12 schooling, such as science (Duncan & Hmelo Silver, 2009) and literacy (Hess & Kearnes, 2011). Typically, such progressions are quite detailed, and deal with the development of specific ideas as a result of engagement in sequences of curricular activities. This perspective thus adds a level of structure to guide the development of coherent curriculum, as well as to inform assessments (i.e., that monitor students' achievement against the expected progression).

Learning progressions for CT and DT can be seen as developmentally specific ways of knowing and learning that manifest CT/DT (i.e., cause or allow those forms of thinking to occur) through informal or designed activities, materials and settings (e.g., Rich, Strickland, Binkowski, Moran, & Franklin, 2018). Learning behaviours and activities found in informal settings include scenarios such as children demonstrating high-level strategic planning and orchestrating skills while playing video games (e.g., Weintrop, Holbert, Horn, & Wilensky, 2016). Those found in designed settings include scenarios such as students demonstrating algorithmic thinking while telling stories using visual programming language in computer science classes (e.g., Seiter & Foreman, 2013). As topics such as CT and DT have entered the curricular context, scholars have turned to the notion of learning progressions as a way of guiding curriculum design according to understandings about student development.

The *CT Teacher Resources,* published by the International Society for Technology in Education and Computer Science Teachers Association (2011), includes a CT progression chart that details performance expectations on nine CT concepts (outlined above) across four grade levels: grades PK to 2, grades 3 to 5, grades 6 to 8, and grades 9 to 12. For example, for the concept of abstraction, 3th-to-5th-graders should be able to "hear a story, reflect on main items, and determine an appropriate title" (p. 8), while 9th-to-12th-graders should be able to "choose a period in politics that was most like the current one by analyzing the essential characteristics of the current period" (p. 8).

Seiter and Foreman (2013) studied the learning progression of CT concepts manifested in existing students' Scratch projects. They analyzed students' projects for evidence of programming skills (i.e., the use of conditionals, partial If statements, complete If-Else statements, and nested If-Else statements) at three different levels: basic, developing, and proficient. Performance variables were further categorized along two dimensions: CT concepts (i.e., procedures and algorithms, problem decomposition, parallelization and synchronization, abstraction, and data representation) and common design patterns in Scratch (i.e., animate looks, animate motion, conversate, collide, maintain score, and user interaction). By analyzing 150 Scratch projects, the authors mapped the application of CT concepts across design patterns at three levels of sophistication. Students at the *basic level* demonstrated capabilities in procedures and algorithms (e.g., sequence and conditional) and data representations (e.g., sprite properties) but lacked capabilities in problem decomposition, parallelization and synchronization, and abstraction. The *developing level* students began to show capabilities in problem decomposition, parallelization and synchronization, and abstraction for some but not all design patterns. At the *proficient level*, students' projects displayed CT practices in almost all design patterns.

Rich, Strickland, Binkowski, Moran, and Franklin (2018) constructed learning progressions for three CT sub-skills: sequence, repetition, and conditionals -- based on a thorough literature review and systematic analysis of reported learning goals and empirical findings at the K-8 level. Each trajectory consisted of sets of learning goals progressing from everyday knowledge to formal computing knowledge. For example, in the sequence trajectory, the *beginning level* included goals like "Precise instructions are more likely to produce the intended outcome than general ones" (p. 51). The *intermediate level* had goals like "The order in which instructions are carried out can affect the outcome" (p. 51). And the *advanced level* involved goals like "Some commands modify the default order of execution, altering when and which instructions are executed" (p. 51).

To date, there has not been much work in the area of learning progressions for DT. The Danish Design Ladder (Kretzschmar, 2003) articulates a four-step model for measuring the level of design activity within an organization: (1) No design; (2) Design as style; (3) Design as process; and (4) Design as strategy. While this ladder has typically been applied outside the educational context, it could provide a means for highlighting the value of design towards enhancing creativity and innovation in problem solving activities.

One source of insight about a learning progression for DT is the difference between expert and novice design thinking (Razzouk & Shute, 2012). For instance, Ho (2001) notes that in developing solutions to design problems, experts decompose the problem into several smaller subproblems for consideration, whereas, novices tend to approach design problems with a "depth-first" approach, in which they quickly narrow it down to a single issue and design to solve that issue. The differences in how experts and novices categorize and approach problems has been a focus of developmental psychology, to account for the process of conceptual change (Chi et al, 1981; Slotta, Chi & Joram, 1995).

To illustrate the progression from novice to expert across a range of DT skills, Crismond & Adams (2012) articulated a model involving (1) a lower anchor that describes assumptions about the prior knowledge and skills of learners and (2) an upper anchor that depicts what learners are expected to know and do by the end of a progression. In this way, Crismond & Adams (2012) lay out the behaviours that move students from a "beginning designer" to an "informed designer":

- **Learning while designing:** Informed designers are involved in continual learning, highlighted by the metacognitive and reflective practice aspects of learning through design.
- **Making and explaining knowledge-driven decisions:** Informed designers use their understanding of physical laws of how things work, of methods of construction, and insights from experiments they conduct to help make and explain their design decisions.
- **Working creatively to generate design insights and solutions:** Creativity and innovation are cornerstones for all design work both in the workplace and in schools.
- **Perceiving and taking perspectives intelligently** Informed designers achieve a perspective on the overarching goals and big picture in a product's development that helps them establish intentions and priorities in their design work.
- **Conducting sustained technological investigations:** Informed designers collect, organize, and analyze evidence and develop critical standards for performing technological investigations and evaluating critical questions related to the device or system they are developing.
- **Using design strategies effectively:** Informed designers possess a range of design practices and strategies, know when and how to use them, and can alter their approaches to accommodate constraints of time and budget. They also work effectively in groups and can decide what information sources to draw upon and what past experiences to apply most effectively when addressing any number of problems embedded in a design challenge.
- **Integrating and reflecting on knowledge and skills:** Informed designers employ an "integrated capability" where action, appraisal, and reflection are used in concert rather than in isolation as they transition among the "intertwined … compound problems" associated with design. They combine skills in design and fabrication with formal and everyday understandings of relevant disciplines to create technological solutions

Finally, the IB MYP design guide includes a learning progression for Design Thinking, organized according to four cycle elements, with specific expectations defined for each of the three MYP years: (1) Inquiring and analyzing; (2) Developing Ideas; (3) Creating Solutions; (4) Evaluating. This tool provides a very useful common reference for IB curriculum designers, and a lens through which they can interpret the efficacy of course designs across the curriculum, in terms of helping students to develop DT.

Key papers in this theme for CT:

- Sengupta, P., Kinnebrew, J., Basu, S., Biswas, G., & Clark, D. (2013). Integrating computational thinking with K-12 science education using agent-based computation: A theoretical framework. *Education & Information Technologies, 18*(2), 351-380.
- Sneider, C., Stephenson, C., Schafer, B., & Flick, L. (2014). Exploring the science Framework and NGSS: Computational thinking in the science classroom. *Science Scope, 38*(3), 10-15. Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology, 25*(1), 127-147.

Key papers in this theme for DT:

- Crismond, D. P., & Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education, 101*(4), 738-797.

- Ho, C. H. (2001). Some phenomena of problem decomposition strategy for design thinking: differences between novices and experts. *Design Studies, 22*(1), 27-45.
- Wrigley, C., & Straker, K. (2017). Design thinking pedagogy: The educational design ladder. *Innovations in Education and Teaching International, 54*(4), 374-385.

Theme 3: Assessment of DT and CT

Key Take-aways

- There is a lack of comprehensive, scalable assessments for DT and CT, partly because the definitions are still being formulated.
- Effective assessments are often formative in nature, providing teachers with a source of insight into students' thinking that can help shape subsequent instruction.
- In using summative, external assessments, care should be taken that required programming languages and/or environments don't impair students' ability to demonstrate competence.

Assessment of CT and DT is of interest to both research and practice. In research, it is concerned with the measurement of these constructs, and evaluation of the success of interventions. In teaching, it is concerned with capturing student progress and (in the case of formative assessment) providing a source of guidance for further progress. Hence, some insight may be gained for K-12 assessment of CT and DT by examining the measures used by researchers in their studies. While conventional approaches may be seen as *assessment of learning*, formative assessment can be understood as *assessment for learning* - meaning that the assessment itself provides a crucial source of information for the student and teacher alike, concerning the student's current state of understanding.

As both CT and DT are relatively new constructs, with definitions that are still evolving and being negotiated, there is a lack of comprehensive, scalable assessments. There have been some efforts to assess CT expertise by appropriating or adapting existing tests such as the Bebras International Informatics contest challenges (Dagiene & Stupuriene, 2016), the Information and Communication Technology Literacy test (Jun, Han, Kim, & Lee, 2014), and the Group Assessment of Logical Thinking test (Kim, Kim, & Kim, 2013). In most of the intervention studies, CT assessments were limited to the specific elements targeted by the interventions. For example, the Computational Thinking Patterns Quiz only assessed students' ability to formulate problems by recognizing computational patterns learned from their prior exposure (Basawapantna, et al., 2011). The Fairy Assessment (Werner, Denner, & Campe, 2012) targeted algorithmic thinking, abstraction, and modeling, but excluded the concept of scaling because the interventions did not address the topic.

Assessing CT

CT expertise has been assessed using student performance on creating computational projects (e.g., Seiter & Foreman, 2013), modifying existing computational artifacts (Werner, Denner, & Campe, 2012), identifying computational patterns in given problems (Basawapantna et al., 2011), creating algorithms or choosing among alternative algorithms to solve a given problem (Roman-Gonzalez, Perez-Gonzalez, & Jimenez-Fernandez, 2017), and solving information-processing tasks (e.g., Dagiene & Stupuriene, 2016). CT assessments were often contextualized within other disciplinary practices.

For example, Weintrop et al. (2014) used mathematical or scientific inquiry scenarios to elicit students' CT practices. These assessment tasks often require multiple steps to complete and involve an integrated set of knowledge and skills. For example, the Fairy assessment requires students to comprehend the narrative underlying the given program, understand the instructions, diagnose bugs, and create new programme or modify the given programme to meet the requirement (Werner, Denner, & Campe, 2012).

Modality effects. Because CT assessments are typically designed to evaluate particular educational interventions, the majority of reported instruments were contextualized in particular programming languages (e.g., Brennan & Resnick, 2012) or computing environments (e.g., Roman-Gonzalez et al., 2017). It should be noted that programming languages or computational environments do affect student performance considerably (Weintrop & Wilensky, 2015). Only a few studies have reported language-independent assessments of CT. For example, the Bebras International Challenge on Informatics and Computational Thinking consisted of tasks that did not require prior experience in computing (Dagiene & Stupuriene, 2016).

Assessing DT

Assessment of DT requires approaches that take into account both the knowledge that students are expected to learn and their more general problem-solving skills (Segers at al., 2003). In a comprehensive review of problem-based and design-based learning environments, Gijbels at al. (2005) outline five characteristics of effective assessments:

- Students' problem-solving skills are evaluated in an authentic assessment environment (i.e., using authentic tasks or problems).
- The tasks are novel to students, asking them to transfer knowledge and skills acquired previously and to demonstrate understanding of the influence of contextual factors on problem analysis and problem solving.
- The analysis task asks students to argue for their ideas on the basis of various relevant perspectives.
- The test items ask for more than the knowledge of separate concepts, stressing the integration of relevant ideas and concepts.
- Assessment of the application of knowledge in the problem-solving design is at the heart of the matter.

The approach of Gijbels at al. (2005) is well suited for DT that is integrated with other domains, as it requires students to demonstrate design thinking in conjunction with the required domain specific knowledge. Well-designed assessments that accommodate the five points above should be able to reveal gaps in students' understanding of the design process and/or their domain knowledge.

An example of a design-based assessment tool can be seen in the work of Barron et al., (1998), who asked 5th grade geometry students to design a "chair for young students". Students were tasked with drawing up blueprints for a carpenter who lived far away and with whom they would not be able to communicate. In this task, students were required to specify all the design information that a builder would need. The task allowed teachers and researchers to effectively assess both the students' understanding of geometry and their design thinking. By carefully designing near transfer assessments (transfer of knowledge from one problem to another within the same subject domain and in a similar fashion), teachers can effectively evaluate students' learning in both the target domain and DT.

Key papers in this theme for CT:

- Basawapatna, A., Koh, K. H., Repenning, A., Webb, D. C., & Marshall, K. S. (2011). Recognizing computational thinking patterns. *Proceedings of the 42nd ACM Technical Symposium on Computer Science Education*, 245-250.
- Dagiene, V., & Stupuriene, G. (2016). Bebras: A sustainable community building model for the concept based learning of informatics and computational thinking. *Informatics in Education, 15*(1), 25-44.
- Werner, L., Denner, J., Campe, S., & Kawamoto, D. C. (2012). The fairy performance assessment: Measuring computational thinking in middle school. In *Proceedings of the 43rd ACM technical symposium on computer science education* (pp. 215-220).

Key papers in this theme for DT:

- Gijbels, D., Dochy, F., Van den Bossche, P., & Segers, M. (2005). Effects of problem-based learning: A meta-analysis from the angle of assessment. *Review of educational research*, *75*(1), 27-61.
- Barron, B. J., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (1998). Doing with understanding: Lessons from research on problem-and project-based learning. *Journal of the learning sciences*, *7*(3-4), 271-311.
- Adams, R. S., Turns, J., & Atman, C. J. (2003, November). What could design learning look like. In *Expertise in Design: Design Thinking Research Symposium* (Vol. 6).

Theme 4. Learning contexts and environments

Key Take-aways

- DT and CT can be applied flexibly to support learning that spans formal and informal contexts, and across subject domains.
- A wide range of platforms can support students in engaging in CT, while far fewer are explicitly dedicated to DT.
- Some environments have been shown to support both DT and CT simultaneously.

Research articles varied widely in terms of their settings, participants and intervention designs. Some were conducted in after school programs or museums (informal learning settings), others in laboratory settings, online environments, and others in classrooms with a variety of student age groups and course topics. The contexts of learning vary within and between studies, and students encounter a wide range of learning environments, from field-based inquiries to technology environments, to small group work, to homework and many other contexts. Even though many of the interventions reported by researchers employed informal environments (after school, museums), their activities and measures are relevant to curricular applications. This section reviews the nature of learning environments used in CT and DT research, in order to draw conclusions about curricular applications and inform the design of new approaches.

For CT, the instructional context often includes existing *industrial-grade computing tools* such as spreadsheets (Sanford & Naidu, 2016; Tahy, 2016; Matsumoto & Cao, 2017) and text-based programming languages such as Python (Hambrusch et al., 2009; R, in Benakli et al., 2017). These environments are often used in higher education and sometimes repurposed to support CT at the K-12 levels as well. *Block-based programming environments* such as Scratch (Brennan & Resnick, 2012), AgentSheet (Repenning, Webb, & Ioannidou, 2010) and MIT App Inventor (Morelli et al., 2011) have become increasingly popular at the K-12 levels, especially for younger students and the after-school settings. Some *block-and-text hybrid programming environments* like Game Maker (Jenson & Droumeva, 2016) have emerged to facilitate the transition from block-based programming to text-based programming. *Robotics construction kits* (Sullivan & Heffernan, 2016) are popular for their tangible, embodied, and interactive nature. *Discipline-based simulations or microworlds* allow learners to explore disciplinary ideas through computational manipulations (e.g., Lattice Land in Pei, Weintrop & Wilensky, 2018; Dynamic Geometry Environments in Sinclair & Patterson (2018); Paper Circuit in Lee & Recker (2018); Multi-Agent-Based computational modeling in Sengupta, Kinnebrew, Basu, Biswas, & Clark (2013). *CT-focused educational games* require students to think computationally and express solutions in algorithms to win the games, such as Light-Bot (Kazimoglu, Kiernan, Bacon, & MacKinnon, 2011). Finally, *Non-computer-based CT-focused activities* also can effectively engage students in CT and are sometimes a referred format of learning to model problems and formulate solutions before jumping into computation (e.g., CTArcade, in T. Y. Lee, Mauriello, Ahn, & Bederson, 2014).

Because DT is largely seen as a cross-disciplinary approach to problem-solving, its application is seen across many domains and settings. DT has been implemented in elementary classrooms (Kangas et al., 2013), middle school geography and engineering classrooms (Carroll et al., 2010; English et al., 2012), AP arts (Watson, 2015), game design classes (Marchetti & Valentine, 2015), makerspaces (Sheridan et al., 2014, Blikstein et al., 2017), and in high school after-school programs and libraries (Scheer et al., 2012; Coleman, 2016). In some cases, DT is integrated into the entire school curriculum. At the Nueva School, a laboratory school located in California, students engage in DT across all aspects of their education, from kindergarten to grade 6 (see a detailed portrayal at their Web site: https://www.nuevaschool.org/academics/design-thinking). While each of these contexts are unique, they all embody the key tenets of DT with students working on authentic problems and engaging in iterative cycles of design and refinement.

While there are relatively few platforms that are expressly designed for design thinking, there are some that appear to be well suited as contexts for DT. For example, FUSE Studio (Jona, Penny & Stevens, 2015), has students engage in design activities in order to "level-up" to increasingly more complex design challenges. FUSE Studio is structured around a free-choice model of instruction in which students follow their own learning pathways. The Scratch programming environment has been used to support creativity and design thinking (Resnick & Rosenbaum, 2013); however, it does not inherently require students to solve problems. As such, the games that students build in Scratch need to have the design process carefully integrated into the building process. MIT's App Inventor focuses more specifically on the DT process, aiming to support students in developing mobile applications that can have a direct impact in students' lives and communities (Tissenbaum et al., 2019).

The learning contexts and environments found in our review were generally non-traditional in nature, meaning that they did not take place in a lecture-oriented classroom setting. Many studies and practitioner reports described the need for a physical learning space that allows students to move about, collaborate spontaneously, engage in short inquiries of their own invention, and creatively push the boundaries of their thinking (e.g., Jona et al, 2015; Brennan & Resnick, 2012).

Students are largely in charge of their own learning activities, constrained by a variety of curricular constructs. These can frequently cut across home, school, after school, and other informal settings. These characteristics are clearly a challenge for assessment, at either the local (i.e., teachers' lesson plans) or programme level (i.e., formal assessments. These activities are typically inquiry-oriented and multi-disciplinary, which runs somewhat counter to the traditional structures of programmes (i.e., courses and topics). Thus, the inclusion of DT and CT as competencies to be assessed will provide new challenges for curriculum designers, similar to those of evaluating other competencies like critical thinking.

Key papers in this theme for CT:

- Sullivan, F. R., & Heffernan, J. (2016). Robotic construction kits as computational manipulatives for learning in the STEM disciplines. *Journal of Research on Technology in Education, 48*(2), 105-128.
- Pei, C., Weintrop, D., & Wilensky, U. (2018). Cultivating computational thinking practices and mathematical habits of mind in lattice land. *Mathematical Thinking and Learning: An International Journal, 20*(1), 75-89.

Key papers in this theme for DT:

- Carroll, M., Goldman, S., Britos, L., Koh, J., Royalty, A., & Hornstein, M. (2010). Destination, imagination and the fires within: Design thinking in a middle school classroom. *International Journal of Art & Design Education*, *29*(1), 37-53.
- Jona, K., Penney, L., & Stevens, R. (2015). 'Re-mediating' Learning. International Society of the Learning Sciences, Inc. [ISLS].
- Kangas, K., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2013). Design thinking in elementary students' collaborative lamp designing process. *Design and Technology Education: An International Journal*, *18*(1).

Theme 5. Teacher practice and professional development

Key Take-aways

- Teachers' pre-existing ideas about DT and CT may inhibit their integration of new forms of practice and classroom discourse
- There is limited research on how teachers come to adopt such new ideas and practices.
- Teacher professional development often employs DT and CT activities, so that teachers learn through doing those activities themselves.
- Teacher support materials should make explicit connections to DT and CT, and show how those forms of thinking (1) are engaged by curriculum, (2) help students develop deep understandings, and (3) require new forms of classroom practice and discourse.

One way to understand teaching practices and inform teacher professional development is to understand effective curriculum, assessments, and learning environments for CT and DT (i.e., the previous three themes). Further progress can be made by understanding the forms of teaching practices that are associated with successful DT and CT instruction. What kinds of discourse and exchange are important within the classroom or online environments? How can teachers support students to work at differing paces, to collaborate and to monitor their own progress? What new pedagogical elements would be required for integrating DT and or CT within a discipline like science or social studies? There is a growing body of research concerned with teacher knowledge and practices concerning CT and DT -- documenting teachers' pre-existing ideas, attitudes and beliefs, as well as their own developmental trajectories. Here, we review what is known about teachers' knowledge and professional development with respect to integrating DT and CT within their teaching practice.

The study of teacher professional development has been guided by theoretical frameworks such as Technological Pedagogical Content Knowledge (Mouza, Yang, Pan, Ozden, & Pollock, 2017; Angeli, Voogt, Fluck, Webb, Cox, Malyn-Smith, & Zagami, 2016), and Actor-Network Theory (Gadanidis, Cendros, Floyd, & Namukasa, 2017). These frameworks allow researchers to comprehensively measure a variety of teacher outcomes including understanding of DT or CT, attitudes towards and beliefs about teaching with DT and CT, and abilities to design curriculum that integrates these competencies. However, there is a lack of research on changes of classroom practices as a result of PD experience

What do teachers need to know in order to teach with DT and CT?

Effective teaching with DT or CT requires teachers to have knowledge about (1) the relevant concepts and practices, (2) learners' difficulties, (3) relevant pedagogical strategies, (4) affordances and limitations of supporting technologies, and (5) the global, local, and classroom context (Angeli et al., 2016). In addition, attitudes and affects towards teaching (e.g., self-efficacy, interest, and perceived importance) were also critical for teachers planning and implementing curriculum that integrated CT or DT.

It is common for teachers to lack a firm understanding of CT or DT, and to possess few clear ideas about how to engage these forms of thinking within their teaching (e.g., Bower & Falkner, 2015). Teachers have been shown to be anxious about their lack of knowledge, capability, confidence, and resources to teach CT (Bower, Wood, Lai, Howe, & Lister, 2017; Gadanidis, Cendros, Floyd, & Namukasa, 2017). One exception to this is seen in computing teachers, who already emphasize CT in their computing classes according to a recent survey (Sentance & Csizmadia, 2017). With respect to teachers' attitudes towards CT, findings from recent studies have been mixed. A few studies found pre-service teachers' attitudes towards CT were difficult to change even though their understanding of CT developed through CT-focused professional development intervention (Yadav et al., 2014; Mouza et al., 2017). Other studies found that non-CS teachers' attitudes toward teaching CT were quite malleable through professional development experiences (Bower, Wood, Lai, Howe, & Lister, 2017).

The primary means of integrating DT have been multidisciplinary, student-centred inquiry and project-based approaches in which learning comes about through cycles of creation and observation (Noweski et al., 2012; Oxman, 2004). To support such learning, teachers need to act as facilitator, connecting DT sub-skills to students' interests and everyday lives. When engaging students in DT, teachers must balance the need to frame tasks through instruction and the need to allow for freedom of designing and constructing their own solution paths (Noweski et al, 2012). Because design-based projects require open-ended problems with multiple solutions, teachers need to understand how to promote divergent thinking (i.e., within their class) during the design process (Dym et al., 2005). This provides an interesting contrast to the notion of convergent thinking, where there is a specific answer or set of answers to a problem. As a result, teachers must reduce their reliance on linear approaches and correct answers and learn to manage and appreciate uncertainty in the solutions students will develop.

Effective teaching with DT also requires teachers to have a strong understanding of the Design Cycle and how it can be integrated within their classroom practices (Glen et al., 2015). Teachers should also be comfortable with practices that support students through the design process such as argumentation (Mathis et al., 2017), design sketching (Kelly, 2017), and in some cases the use of tools for 3D design, storyboarding, and graphic design (O'Byrne et al., 2018; Nottingham, 2017).

Araujo et al. (2016) argue that for teachers to engage their students in DT, it is not enough for them to simply present problems to students that are open-ended; they must also help students design for "purpose". Further, this purpose needs to be both important to the student and directed in ways that can make a difference in the world. Tissenbaum et al (2019) have similarly advocated for an approach to CT and DT together in which students design computational solutions to problems that have a direct impact in their lives and those in their communities. Having students develop solutions that connect directly to their lives can help them develop their computational and design identities, which will in turn influence their pursuit of career paths that involve DT & CT.

What Professional Development strategies have been identified?

A number of promising strategies have been identified, to help teachers develop knowledge and experience with DT and CT integration. First, teachers must be helped to overcome any negative attitudes and emotions towards CT (i.e., fear or anxiety) by fostering a growth mindset, throughout professional development experience (Gadanidis, Cendros, Floyd, & Namukasa, 2017). For non-computing teachers, CT should be introduced within their own subject domains to make it clear how CT can be *integrated into disciplinary learning* (Yadav et al., 2014). The literature also suggests the need to provide grade-specific professional development, because DT and CT can look and feel very different for students of different age ranges.

For teachers with no computing background, these competencies can be introduced through everyday examples (e.g., how to provide driving directions or how to fix a dysfunctional lamp, Yadav et al., 2014) and beginner-friendly computing environments such as block-based programming languages (e.g., Scratch, in Cetin, 2016). Having teachers "test-drive" established learning activities in professional development workshops can boost their knowledge and self-efficacy of teaching with DT or CT. Also emphasized is the need to provide and maintain high-quality teaching resources to help teachers improve their ability and confidence (Bower & Falkner, 2015; Barr & Stephenson, 2011). Finally, it is important to provide a curriculum framework and challenge the teachers to design their own lessons, to deepen their understanding and promote enduring curriculum change. For pre-service teachers or in-service teachers seeking advanced education, courses in technology integration are often well-suited to help them consider new ways of integrating student-centred learning and inquiry, and could be leveraged to introduce DT and CT as well (Yadav et al., 2017; Mouze et al., 2017).

Some professional development approaches have been shown to help teachers develop an accepted CT as a cross-disciplinary way of thinking, a form of literacy. Gadanidis, Cendros, Floyd, & Namukasa (2017) related CT to not only disciplinary learning for teachers, but also the development of a growth mindset in teaching. However, many teachers still tended to focus on using computational tools as an engagement strategy instead of way to develop and engage their students' CT and deepen disciplinary learning (Gadanidis et al., 2017; Bower & Falkner, 2015). There is also persistent gap between teachers' knowledge of CT and their application and implementation of CT (Mouza et al., 2017).

There have been a number of strategies suggested to support teachers in developing the understanding and skills necessary to integrate DT within their classroom practices. One popular approach is to have teachers engage in DT themselves during their professional development and training. Araujo et al. (2016) had undergraduate teacher candidates and teachers-in-service solve design-based problems in their school communities. O'Byrne et al. (2018) had pre-service teachers explore creativity and divergent thinking through the creation of stop-motion movies as a way for them to integrate a DT philosophy into the teaching. When designing curriculum that integrates DT, some researchers have advocated for teachers to employ pre-existing approaches, such as Stanford's d.school design thinking bootleg (https://dschool.stanford.edu/ resources/ design-thinking-bootleg; Melles et al., 2012; Bowler; 2014). Through this approach, teachers can develop knowledge of the design process, various tools for enacting each of the steps, and how to overcome roadblocks or challenges that students might face along the way.

Key papers in this theme for CT:

- Angeli, C., Voogt, J., Fluck, A., Webb, M., Cox, M., Zagami, J., … Zagami, J. (2016). A K-6 computational thinking curriculum framework: Implications for teacher knowledge. *Educational Technology & Society*, *19*(3), 47–57.
- Yadav, A., Mayfield, C., Zhou, N., Hambrusch, S., & Korb, J. T. (2014). Computational thinking in elementary and secondary teacher education. *ACM Transactions on Computing Education*, *14*(1), 1–16. https://doi.org/10.1145/2576872
- Deschryver, M. D., & Yadav, A. (2015). Creative and computational thinking in the context of new literacies: Working with teachers to scaffold complex technology-mediated approaches to teaching and learning. *Journal of Technology and Teacher Education*, *23*(3), 411–431.

Key papers in this theme for DT:

- Noweski, C., Scheer, A., Büttner, N., von Thienen, J., Erdmann, J., & Meinel, C. (2012). Towards a paradigm shift in education practice: Developing twenty-first century skills with design thinking. In *Design thinking research* (pp. 71-94). Springer, Berlin, Heidelberg.
- Johns, G., & Mentzer, N. (2016). STEM integration through design and inquiry. *Technology and Engineering Teacher*, *76*(3), 13.
- Mentzer, N., Farrington, S., & Tennenhouse, J. (2015). Strategies for teaching brainstorming in design education. *Technology and Engineering Teacher*, *74*(8), 8.
- Bowler, L. (2014). Creativity through "maker" experiences and design thinking in the education of librarians. *Knowledge Quest*, *42*(5), 58.

Section 2

How are Design and Computational Thinking Currently Incorporated in IB Programmes?

Document Analysis

Section 2: How are DT and CT Currently Incorporated in IB Programmes?

Key take-aways

- All programs emphasize real-world problems, any many courses include a focus on open-ended problems, creativity and design.
- Collaboration is named as a value, especially in the MYP, but is not often addressed with any explicit guidance, nor is it explicitly evaluated.
- Iterative improvements and the design cycle are of central importance in the MYP, but again, not often included with specific guidance or examples in the TSM.
- Many elements of DT and CT are found within the course materials, but these were incidental, occurring because of pre-existing values (i.e., of inquiry), and not because DT or CT had been targeted explicitly.

To address our research question about how DT and CT are currently included in the three programmes, we performed a curriculum audit, reading and coding selected courses and program-level documents according to our working definitions. Our coding focused on three elements of each course: (1) the course guide, (2) the teacher support materials and (3) selected assessments and specimen papers. Our overarching goal was to understand the extent to which courses in each of the three programmes included specific reference to DT/CT, as well as guidance for teachers. While there has not yet been any overt move on the part of the IB to include DT and CT (i.e., as being explicitly named and defined within the various programme descriptors), we recognized that there is already an awareness of the priority to foster these competencies (particularly DT), and -- given our working definitions -- plenty of ways in which particular elements of DT and CT (e.g., collaboration, or abstraction of problems) would show up within the courses and materials.

We also sought to identify opportunities where DT and CT could be included more directly, or where guidance could be improved. Two primary sources of data presented in this report.

(1) Qualitative coding of the course documents, performed according to the specific elements of our working definitions, which offers a means of looking into each course, as well as across the entire course and programme, to assess its degree of inclusion and support of DT and CT.

(2) A holistic assessment of each course and program, informed by the coders' open notes taken about each major document section. In other words, after performing the coding, we generated a synthesized narrative to discuss how we saw DT and CT appearing throughout the course materials, and opportunities for improving this guidance and support (discussed in Method below). These synthesizing notes can be combined with the more formal coding to gain a better sense of how DT and CT are addressed and where there may be opportunities for improvement.

Method (document analysis)

We coded six courses for DP: Chemistry, Physics, Geography, Computer Science, Design Technologies, and Mathematics (Applications and Interpretation). Four courses were coded for the MYP: Sciences, Design, Individual and Societies, and Mathematics. For the PYP, we coded the Learning and Teaching document, as well as the Scope and Sequence documents for Mathematics, Social Studies, and Science. The documents looked at included course guides, selected teacher support materials and assessment specimen exams and/or assessment sections of the PYP.

For each course, or Scope and Sequence document, we worked closely with the IB Research office to identify relevant subsections of the Guide, Teacher Support Materials, and Assessments (including student specimen papers). We coded each of those subsections for the *presence* (explicit, implicit, none, or not applicable) of *all* dimensions of our working definitions. For DT, these were: (1) Grounded in real world, open-ended problem, (2) Collaboration is emphasized, (3) Creative processes are emphasized, and (4) An iterative design cycle is emphasized. For CT, these elements were: (1) Formulation of a problem, (2) Decomposition of the problem, (3) Abstraction, (4) Algorithms, (5) Testing & Debugging, (6) Iteration. A 7th dimension, Transfer, was omitted, under consultation with IB research, given that it appeared quite rarely in any coding.

In addition to *Presence,* we also coded each of these 10 dimensions in terms of *Guidance sufficiency* (sufficient, insufficient, or none), and *Opportunity for linking to DT/CT* (high, low or not applicable). See Figure 4 below. Throughout the coding process, we also recorded open ended notes regarding the strengths, weaknesses, and opportunities for improving the course with regard to its inclusion of CT and DT. These notes supported a grounded discussion of the course within our team, including opportunities for future developments. All of these codes and notes were compiled within the same Excel sheet, which became the basis for our analysis. We first constructed a summary of all codes for each course, then synthesized these across all courses that were coded within each program. This approach provided a set of summary statistics that could reveal the basic presence, guidance, and opportunities for inclusion of DT and CT within the various IB Programs. These data and analysis are presented in the sections below, as our means of addressing the research question.

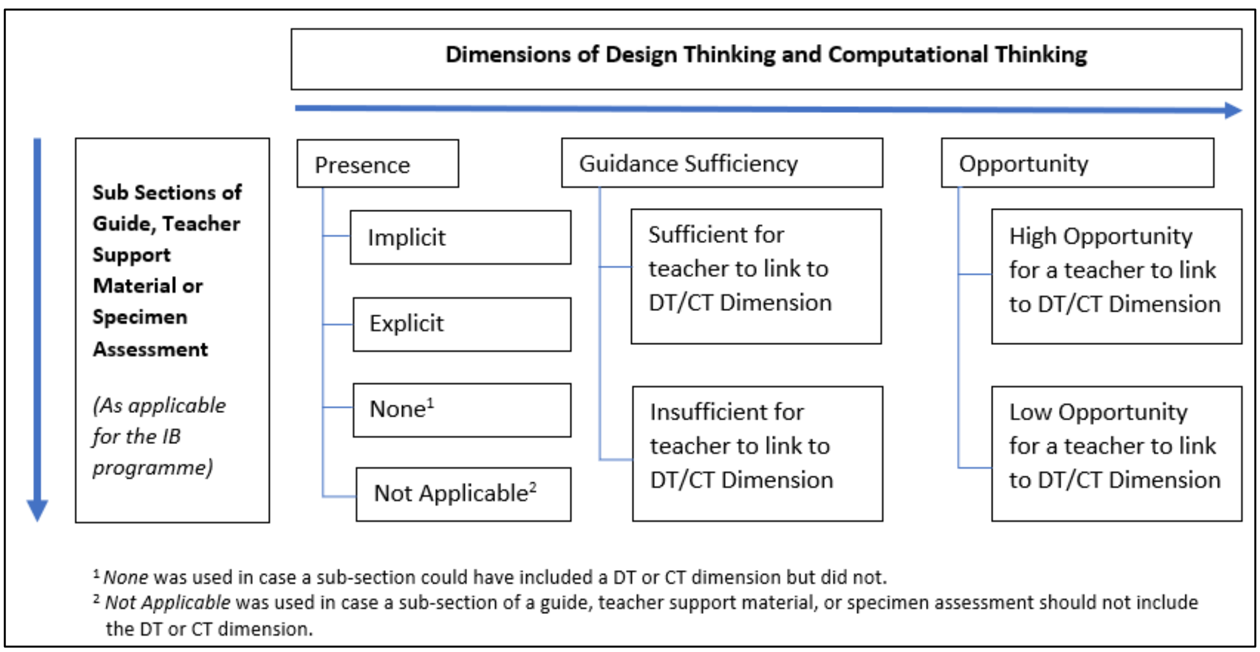
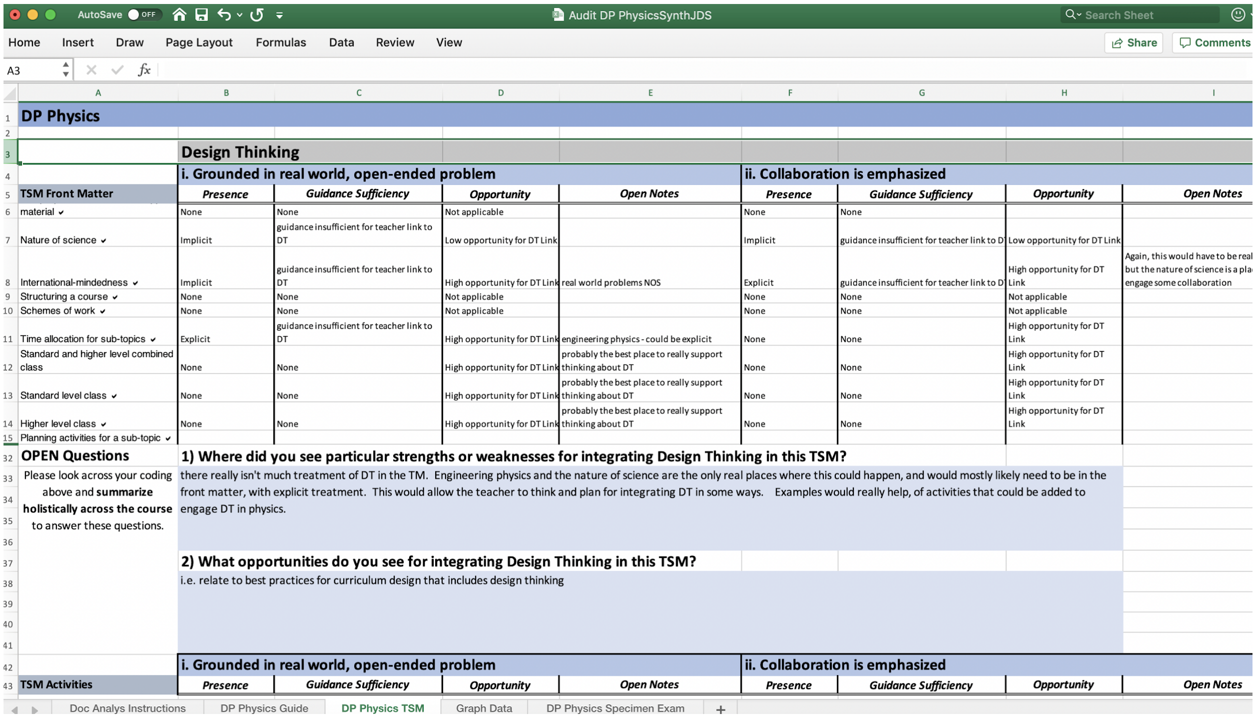


Figure 4. Coding scheme applied to sections of guides, TSM and assessments.

We developed an Excel spreadsheet (See Figure 5) to support our recording of these measures, with one row for each of the assigned subsections of the various course documents. Figure 5 presents a schematic view together with an actual screen image of that spreadsheet, showing dimensions of DT across the top (i.e., the columns), with 3 measures (*Presence*, *Guidance* and *Opportunity)* and a note for each dimension. Not shown in the schematic (but visible in the lower image) are two additional fields to collect notes for each major section: (1) *Where did you see particular strengths or weaknesses for integrating DT/CT?*, and (2) *What opportunities do you see for integrating Design Thinking?* The image shows our coding of 10 sub-sections of the TSM for the DP physics course. Only the first two dimensions of DT (real-world problems, and collaboration) are visible.



DP Physics								
	Design Thinking							
	i. Grounded in real world, open-ended problem				**ii. Collaboration is emphasized**			
TSM Front Matter	*Presence*	*Guidance Sufficiency*	*Opportunity*	*Open Notes*	*Presence*	*Guidance Sufficiency*	*Opportunity*	*Open Notes*
material	None	None	Not applicable		None	None		
Nature of science	Implicit	guidance insufficient for teacher link to DT	Low opportunity for DT Link		Implicit	guidance insufficient for teacher link to D	Low opportunity for DT Link	
International-mindedness	Implicit	guidance insufficient for teacher link to DT	High opportunity for DT Link	real world problems NOS	Explicit	guidance insufficient for teacher link to D	High opportunity for DT Link	Again, this would have to be real but the nature of science is a pla engage some collaboration
Structuring a course	None	None	Not applicable		None	None	Not applicable	
Schemes of work	None	None	Not applicable		None	None	Not applicable	
Time allocation for sub-topics	Explicit	guidance insufficient for teacher link to DT	High opportunity for DT Link	engineering physics - could be explicit	None	None	High opportunity for DT Link	
Standard and higher level combined class	None	None	High opportunity for DT Link	probably the best place to really support thinking about DT	None	None	High opportunity for DT Link	
Standard level class	None	None	High opportunity for DT Link	probably the best place to really support thinking about DT	None	None	High opportunity for DT Link	
Higher level class	None	None	High opportunity for DT Link	probably the best place to really support thinking about DT	None	None	High opportunity for DT Link	
Planning activities for a sub-topic								
OPEN Questions	**1) Where did you see particular strengths or weaknesses for integrating Design Thinking in this TSM?**							
Please look across your coding above and **summarize holistically across the course** to answer these questions.	there really isn't much treatment of DT in the TM. Engineering physics and the nature of science are the only real places where this could happen, and would mostly likely need to be in the front matter, with explicit treatment. This would allow the teacher to think and plan for integrating DT in some ways. Examples would really help, of activities that could be added to engage DT in physics.							
	2) What opportunities do you see for integrating Design Thinking in this TSM?							
	i.e. relate to best practices for curriculum design that includes design thinking							
	i. Grounded in real world, open-ended problem				**ii. Collaboration is emphasized**			
TSM Activities	*Presence*	*Guidance Sufficiency*	*Opportunity*	*Open Notes*	*Presence*	*Guidance Sufficiency*	*Opportunity*	*Open Notes*

Figure 5. Screen capture of the Excel coding sheet, showing the first 2 dimensions for coding DT.

It is important to note that coding such as this has limitations with regards to interpretation and reliability. Such coding can never be achieved perfectly, as subjective expert judgement is required in each case (e.g., whether a dimension of DT or CT was explicitly or implicitly present in a section of the TSM). However, the present coding is sufficiently coarse-grained (e.g., judgements of "high" vs "low" vs "none") that it is likely quite reliable. In preparation for the audit coding, the three authors jointly coded three courses, each taking the lead on one and serving as second coder on another. This provided a means of collaboratively developing the coding rubrics, norming our coding method and identifying any issues about reliability of coding. It is important to remember that our discussion of these courses is only informed by the specific documents provided to us for audit. We had no access to any materials developed by schools and teachers, so that any discussion we offer is limited to the materials that we read for the audit. In some cases, our readings showed explicit mention of DT within the guides (e.g., in Math and Science) -- where design thinking is highlighted as an important element of the course, but then much less explicit mention in the remainder of materials.

The next three sections present a summary of the high-level audit results for the three programs. Each section begins with a set of three tables, one each for *the Presence* of DT/CT, the *Guidance sufficiency*, and the *Opportunity for links*. To arrive at the scores within these tables, we pooled all codes across: (1) all dimensions of DT and CT, respectively, and (2) all sections of all documents within a given course. We then calculated the percentage of each score element (e.g., for "presence": what percentage of all scores were Explicit, Implicit, and None). We used the percentage measure to offer some normalization across courses and programs, because the overall number of sections that were coded within any given course (e.g., of TSMs) was quite variable. Because the code totals varied considerably across courses and programmes, it was difficult to perform comparisons or look for patterns.

The use of percentages can only describe how frequently a certain code occurred *in relation* to the total number codes for that course. Thus, values in the Tables below often include fairly low scores for the presence of CT and DT (e.g., 10%), and high scores for "none" – but these low percentages should not be interpreted as a fraction of what should be, since not every section of a document should be expected to show explicit presence of every dimension of CT or DT. Hence, many sections scored "none" for most or all the dimensions. While this level of aggregation (i.e., across all dimensions and coded sections) and the percentage measure may occlude some detail, it allows for comparison across the courses and programmes. The full coding, together with qualitative summaries and discussions of all courses is provided in Appendix C. These course summaries explore the nuances of how each course treats CT and DT, in the guides, TSM and assessments. But the 14 summaries present too much volume to be included in the body of the report.

The Diploma Programme

The diploma programme (DP) courses are characterized by an advanced level of content, both in depth and breadth of coverage. The assessments target at a high level of content mastery. Course materials follow a common structure for the Guides and Teacher Support Materials (e.g., the Nature of the subject, connections to the MY program, interdisciplinary and inquiry-oriented approaches). There is strong level of coherence amongst the courses, and a thoughtful treatment of the epistemic nature of the disciplines.

Taken together, the Tables 1, 2, and 3 provide some insight about the overall presence of CT and DT across the Diploma Programme. Table 3 describes the *Opportunity* codes, pooled across all sections and dimensions. While the row for DP Math shows more than 70% of coded sections were "Not Applicable" for links to CT or DT, all other courses show much lower scores for "N/A". Overall, more than 50% of all sections coded were seen as holding some opportunity for links to DT and CT. This means that there was ample opportunity identified, across the programme. The detailed discussions provided in Appendix C are common in recognizing that the breadth of content covered by DP courses interferes with the ability to include elements of DT and CT. This makes sense, as each of these on their own require some time and space for students to work deeply and creatively, with iterative cycles of evaluation and revision. We recognized that in their present forms, there may be little space within the curriculum to allow for such creativity, iterative refinement and open-ended processes. A survey of DP teachers, presented in Section 3 below, supports that interpretation. However, we did identify opportunities for every course where connections to CT and DT could be improved (see Appendix C for specific course summaries).

In Table 1, there is an expected higher percent score for *Presence* of DT within the Design Tech course (25%) than the other courses (which average 12%). Unexpectedly, however there was no corresponding increase in the *Presence* of CT for the Computer Science course. Overall, we see that CT dimensions are much less likely to be *Explicitly present*" (8% total) than they are to be *implicitly present*" (23% total). Hence, DT dimensions are apparently easier to address explicitly in the DP guides than CT dimensions. Finally, a lack of clear *Guidance* was observed for DT and CT dimensions. In more than 2/3 of all occasions where *Guidance* was present for DT, it was deemed *Insufficient* (20% vs 9%). For CT, more than 5/6 of all occasions were deemed *Insufficient* (27% vs 5%). Overall, these data suggest that the DP is challenged to make explicit connections to CT and DT, most likely because of heavy content demands, with a low overall occurrence, but many places where possible links to DT and CT could be identified.

Table 1. Percentage of *Presence* of DT and CT across all coded materials.

Course Name	DT Presence (%)			DT Total	CT Presence (%)			CT Total
	Explicit	Implicit	None		Explicit	Implicit	None	
Geography	12%	26%	62%	196	12%	14%	74%	292
Computer Science	14%	14%	71%	259	12%	15%	73%	390
Math A & I	9%	5%	85%	392	6%	10%	84%	588
Physics	11%	25%	63%	228	7%	33%	60%	372
Chemistry	8%	14%	78%	288	10%	34%	56%	432
Design Tech	25%	14%	61%	232	6%	35%	59%	348
Total all DP	**13%**	**15%**	**72%**	**1595**	**9%**	**23%**	**69%**	**2422**

Table 2. Percentage of *Guidance Sufficiency* of DT and CT across all coded materials

Course Name	DT Guidance Sufficiency (%)			DT Total	CT Guidance Sufficiency (%)			CT Total
	Sufficient	Insufficient	None		Sufficient	Insufficient	None	
Geography	3%	19%	79%	196	2%	9%	89%	292
Computer Science	11%	11%	78%	259	7%	11%	82%	390
Math A & I	3%	8%	89%	392	4%	9%	87%	588
Physics	0%	38%	62%	228	0%	44%	56%	372
Chemistry	9%	25%	66%	288	9%	41%	50%	432
Design Tech	27%	17%	56%	232	6%	40%	54%	348
Total all DP	**8%**	**18%**	**73%**	**1595**	**5%**	**27%**	**69%**	**2422**

Table 3. Percentage of *Opportunity for Links* of DT and CT across all coded materials.

Course Name	DT Opportunity for Links (%)			DT Total	CT Opportunity for Links (%)			CT Total
	High	Low	N/A		High	Low	N/A	
Geography	32%	12%	56%	196	24%	17%	58%	292
Computer Science	29%	23%	48%	259	27%	25%	48%	390
Math A & I	19%	17%	64%	392	22%	20%	58%	588
Physics	25%	64%	11%	228	37%	53%	10%	372
Chemistry	23%	12%	66%	288	19%	33%	48%	432
Design Tech	38%	16%	47%	232	25%	27%	48%	348
Total all DP	**27%**	**23%**	**51%**	**1595**	**25%**	**29%**	**46%**	**2422**

Looking across the detailed coding and summaries for these 6 courses (Appendix C), we recognize a common commitment to grounding instruction in real-life problems, and connecting course content across disciplines. While there were many places within the course guides and teacher support materials that made implicit connections to the dimensions of our working definitions, very few explicit connections were made. In most cases, we found the guidance to be insufficient to support teachers in fostering students' CT and DT within their instruction. In many cases, we recognized opportunities for DT and CT to be addressed. Even the addition of some explicit reference to DT and CT as instructional priorities would likely help teachers understand the need to include them as instructional priorities. Identifying DT and CT as objects of assessment would also be an effective means of ensuring that teachers addressed them.

Sustained inquiry processes such as modeling, testing, debugging and revising are less prominent within courses like physics, mathematics and chemistry -- presumably because they require more instructional time. Collaboration is sometimes named as a value in the guides, but does not often show up explicitly within the course guidance. In general, design was more prominent than computational thinking in our coding, presumably because it is a "softer" skill, with a broader range of inquiry activities addressing its dimensions. For example, most DP courses expressed a clear value for real world connections and problem solving. Computation was more challenging to integrate, given the more structural dimensions of problem formation, reduction, abstraction and algorithms.

The Middle Years Programme

The Middle Years Programme (MYP) courses are characterized by a high level of interdisciplinarity, a focus on project work, and emphasis of design and creative thinking. In our view, the MYP was very strongly positioned to help students engage in design thinking, although computational thinking was less well developed within these courses. It also appeared that there was substantial flexibility for teachers to include inquiry activities and build cross disciplinary connections. Presumably, this is due to a lower burden of content coverage, which we identified as a barrier in our audit of some DP courses. One feature of the MYP that seemed promising for the support of DT and CT is the use of multimedia e-Assessments, which could allow for more computational features, as well as modeling testing and iterative elements. MYP also includes an e-portfolio option, which seems like a potential support for the assessment of DT and CT. In particular, and naturally, the MY Design course appears to offer explicit treatment of most DT dimensions, although the dimensions of collaboration and iteration are represented less explicitly in the TSM.

Table 4 reveals that the MYP has a substantially improved *Presence* of DT, but approximately the same *Presence* of CT, as compared to the DP above. In particular, and as expected the Design course showed an extremely high level of explicit *Presence* for DT, with 46% (i.e., across all sections, for all 4 dimensions of DT). *Guidance* scores (Table 5) were appreciably higher for DT than they were in the Diploma Programme, but approximately the same with regard to CT. The ratios of *insufficient Guidance* to *sufficient Guidance* were approximately the same as those identified for the DP (i.e., 2/3 for DT and 5/6 for CT). Notably, the *Opportunity for links* in the MYP courses (Table 6) was dramatically higher than it was for DP courses. Opportunities abounded, in our coding, for MYP courses to make such connections, for both DT and CT. Presumably, this is because of the greater level of inquiry, collaboration, and projects that are present in DP, and lower levels of content to cover within any given course.

Table 4. Percentage of *Presence* codes across all coded materials

Course Name	DT Presence (%)			DT Total	CT Presence (%)			CT Total
	Explicit	Implicit	None		Explicit	Implicit	None	
Math	15%	16%	70%	224	12%	22%	66%	336
Science	27%	25%	48%	157	6%	28%	65%	240
Individuals and Society	17%	38%	45%	108	1%	23%	76%	162
Design	46%	15%	40%	124	10%	38%	52%	185
Total all MYP	**25%**	**22%**	**54%**	**613**	**8%**	**27%**	**65%**	**923**

Table 5. Percentage of *Guidance Sufficiency* codes across all coded materials

Course Name	DT Guidance Sufficiency (%)			DT Total	CT Guidance Sufficiency (%)			CT Total
	Sufficient	Insufficient	None		Sufficient	Insufficient	None	
Math	10%	10%	79%	224	9%	11%	79%	336
Science	0%	35%	65%	157	0%	23%	77%	240
Individuals and Society	0%	53%	47%	108	0%	38%	62%	162
Design	48%	15%	37%	124	11%	41%	48%	185
Total all MYP	**13%**	**25%**	**62%**	**613**	**6%**	**25%**	**69%**	**923**

Table 6. Percentage of *Opportunities for Links* codes across all coded materials

Course Name	DT Opportunity for Links (%)			DT Total	CT Opportunity for Links (%)			CT Total
	High	Low	N/A		High	Low	N/A	
Math	33%	18%	49%	224	35%	24%	41%	336
Science	57%	23%	20%	157	8%	83%	9%	240
Individuals and Society	77%	15%	8%	108	6%	88%	6%	162
Design	62%	3%	35%	124	33%	21%	46%	185
Total all MYP	**53%**	**16%**	**32%**	**613**	**22%**	**50%**	**28%**	**923**

Similarly, there was a notable lack of *Collaboration* codes within the MYP, although collaboration was stressed explicitly as a value within the guide. Similarly, while iterative improvements or design revisions are described, that process of iteration appeared very rarely in the remainder of the course materials. In other words, there were few examples and little explicit guidance about how teachers could integrate these dimensions of DT.

While there were low overall scores for *Presence* and *Guidance Sufficiency* of CT dimensions, our coding revealed a high level of *Opportunities* where CT could be added. Computation occurs regularly in the process of design, including digital layout and prototyping, modeling and many elements of robotics and micro-processing (e.g., Arduino). The rise of makerspaces has engaged students in many forms of computational thinking, as they learn to "hack their lives" and embed computation into the world around them. We suspect that MY instructors do regularly engage in such practices within their courses (e.g., in design projects), but these references are absent from the MYP materials that we coded. It would be straightforward to add explicit reference to design and computational thinking into the Guides and TSM (e.g., *Decomposition* and *Algorithms*, as well as *Patterns*). But ideally there would be guidance about how to make such connections and include them as elements of the course. For example, in a design project, students could be Engaged in thinking about higher-level design practices and rules, as a means of adding *Abstraction.* In general, the addition of a computational aspect to any inquiry project would likely strengthen both DT and CT, as well as the intersection of the two.

There is great opportunity for connecting to DT and CT, as a result of the interdisciplinary nature of MYP, and the MY projects in particular. Given the high value placed on real world problems and connections, it should be straightforward to highlight DT within various sections of the guide, clarifying for teachers that such thinking is a priority and aim of instruction. In the Science course, for example, "Teaching and Learning through Inquiry" section could make an explicit connection to both DT and CT, adding these into the Key concepts. This section currently does not offer much information about *how* inquiry can be used to help students achieve understanding of these concepts (e.g., in Systems, Change, Interactions). This could be improved by highlighting DT and CT as prominent forms of thinking that are engaged by inquiry and through inquiry can achieve its goals of deep understanding. Dimensions like *Collaboration*, *Testing & Debugging*, and many other elements of CT and DT are common to inquiry, generally. MYP teachers could benefit from a deeper discussion of how inquiry proceeds, and design and computation could be introduced as key strategies.

The Primary Years Programme

The Primary Years Programme is characterized by a theoretical commitment to transdisciplinary learning, according to 6 core themes (e.g., "How the world works), with a framework that guides the development of inquiry-oriented curriculum. Curriculum is characterized by a high level of flexibility for teachers to develop inquiries that support student progressions. For each theme, a set of core concepts is articulated for each of three different age ranges: (1) Age 3-5 Years, (2) age 5-7 years, and (3) age 7-9 years. Teachers within a school are expected to work together to define and iteratively improve a set of curricular inquiries that engage students according to these themes and concepts. The PYP Learning and Teaching Guide is exceptional in its depth of treatment of teaching practices, providing guidance for transdisciplinary approaches, and specific practices that support student agency and foster skills development.

A central goal of the PYP is to foster student agency and self-regulation, preparing students for later programmes and successful academic life. The PYP specifies a set of five interrelated skills and subskills that are as important to address as any conceptual topics: (1) Thinking skills, including critical-thinking and creative-thinking skills; (2) Research skills, including Information and media literacy skills; (3) Communication skills, including literacy and ICT skills; (4) Social skills, including interpersonal relationships and collaboration skills; and (5) Self-management skills, including time management, self-motivation and resilience. Taken together, the PYP guides define a programme with the capacity to support a breadth of learners and contexts, including support for teachers and a broader school community. The emphasis on child development and teaching and assessment practices are exemplary.

Students' development of DT and CT are addressed explicitly in the Learning and Teaching document, as well as the Technology integration guide, and are highly commensurate with the PYP framework. Of all three programmes, the PYP had the highest level of *Opportunity* for connections to CT and DT (Table 9). The *Presence* of DT and CT (Table 7) are both dramatically higher than other programmes. *Guidance Sufficiency*, however, is notably still lacking, with roughly the same ratios of *sufficient* -to-*insufficient* (Table 8). In regard to the documents we coded, this programme was in excellent position to strengthen the linkage to, and guidance for CT and DT, and teachers could again benefit greatly from such guidance.

The notions of a PYP learner, including agency and self-efficacy within a community of learners, are consistent with autonomous inquiry, design and the use of computation to address problems. Thus, it is clear that DT and CT could be well aligned with the PY programme. Transdisciplinary themes are a strength, inviting connections to the real world, as well as collaboration and creativity (e.g., "Sharing the planet", "How the world works", "Where we are in place and time" and "How we express ourselves"). The open-ended nature of the programme of inquiry, and the fact that it bridges the early and primary years, allows schools to create a community of learners in which design thinking could be fostered.

One consideration would be to be explicate the connections to CT and DT within these guides, weaving in guidance about how to support these forms of inquiry and cognition. Discussions of the learner profile or transdisciplinary learner, for example, could be well suited for the inclusion of DT and CT as important competencies.

Table 7. Percentage of *Presence* codes across all coded materials

Course Name	DT Presence (%)			DT Total	CT Presence (%)			CT Total
	Explicit	Implicit	None		Explicit	Implicit	None	
Math	17%	17%	67%	60	13%	22%	64%	90
Learning & Teaching	46%	31%	24%	72	6%	20%	73%	108
Science	22%	75%	3%	32	44%	48%	7%	54
Social Studies	10%	30%	60%	40	0%	28%	72%	60
Technology Integration	25%	0%	75%	16	17%	8%	75%	24
Total all PYP	**26%**	**31%**	**43%**	**220**	**14%**	**26%**	**60%**	**336**

Table 8. Percentage of Guidance Sufficiency codes across all coded materials

Course Name	DT Guidance Sufficiency (%)			DT Total	CT Guidance Sufficiency (%)			CT Total
	Sufficient	Insufficient	None		Sufficient	Insufficient	None	
Math	10%	23%	67%	60	20%	16%	64%	90
Learning & Teaching	4%	72%	24%	72	6%	22%	72%	108
Science	0%	97%	3%	32	0%	100%	0%	54
Social Studies	10%	48%	43%	40	0%	28%	72%	60
Technology Integration	0%	25%	75%	16	0%	25%	75%	24
Total all PYP	**6%**	**55%**	**40%**	**220**	**7%**	**34%**	**59%**	**336**

Table 9. Percentage of Opportunity for Links codes across all coded materials

Course Name	DT Opportunity for Links (%)			DT Total	CT Opportunity for Links (%)			CT Total
	High	Low	N/A		High	Low	N/A	
Math	32%	38%	30%	60	47%	28%	26%	90
Learning & Teaching	47%	53%	0%	72	14%	85%	1%	108
Science	22%	78%	0%	32	35%	65%	0%	54
Social Studies	35%	28%	38%	40	10%	20%	70%	60
Technology Integration	100%	0%	0%	16	21%	79%	0%	24
Total all PYP	**41%**	**44%**	**15%**	**220**	**26%**	**54%**	**20%**	**336**

The PYP Scope and Sequence guides (published in 2008 and 2009 and currently under extensive review) are explicit in their emphasis of collaboration and creativity. Finding solutions through action is another principle that is consistent with design thinking as well as computational thinking. The focus on concepts and conceptual understanding would also lend itself nicely to design oriented activities (inquiries). The notion of multiple interacting literacies -- including technology literacy - is another very good way to build these connections. Technology and information literacy are already introduced as an important dimension of young learners' development, as evidenced by the excellent (if limited) Technology Integration guide. For early learners, teachers and parents might consider introducing students to algorithmic thinking using tangible objects, which students could manipulate by following symbols or sounds or basic coding principles. Learners with more developed algorithmic skills could be engaged with programming environments such as Logo, Alice, Scratch, and so on.

The guide offers a deep treatment of the transdisciplinary nature, and how to craft a programme of inquiry, which would offer opportunities to integrate DT and CT. Information skills and media literacy skills are already nicely explicated and unpacked for teachers, with guidance on how to integrate them within student inquiries. This would be a good way to include CT and DT as well. In the Inquiry section of the guide, there are many implicit references to testing theories and experimenting that would be consistent with CT; while these do not explicitly recognize CT, they would be a very suitable place to introduce such language. The "developing a programme of inquiry" section would also be a great place to add guidance for how teachers could integrate design and computational thinking. Presumably, the Assessment section of the Learning and Teaching guide, which is superb, might also add some explicit treatment of CT and DT, as "ways of thinking" that would be assessed according to the PYP model. The focus on teaching practices in the guide, particularly around the approaches to developing inquiries, offers a very good place to insert some treatment of DT and CT. The Approaches to Learning section offers another good place to introduce treatment and guidance of DT and CT.

Discussion

Across the IB programmes, there is a clear value placed on design, problem solving, collaboration and inquiry-oriented learning. While the DP clearly has some level of tension in regard to the broad content coverage and time limitations, there are clear connections made between programmes, suggesting an ongoing progression of the learnings emphasized in the PYP Learning and Teaching guide. In our reading and coding, summarized in the Tables above and detailed in Appendix E, we saw considerable connections to the five dimensions of DT and CT, and many opportunities to improve linkages and guidance. But there was very little specific mention of the dimensions or full constructs of DT or CT (i.e., by name), which is understandable given that they have only come to broad recognition in the past decade. Thus, guides and materials may still not have fully incorporated the competency-centred language in which DT and CT are typically embedded.

In the DP and MYP we feel that new versions of the Guides and TSM would be well positioned to make explicit connections to DT and CT, as well as to offer some insight about the learning progressions that would engage DT and CT as instructional priorities. The guides could also describe the relevance of DT and CT to the instructional domain. Corresponding sections could be added to the TSM to offer insight into supportive teaching and assessment practices. CT in particular could be connected with the wider goal of technology integration – i.e., by helping DP teachers integrate technology learning environments such as Nearpod or Padlet or Google Drive, in which they will need to think more actively with technology, collaborate with peers, and struggle with the usual issues of user interfaces, files and versions, editing permissions, etc. While these elements may not be explicitly engaging computation, they will add some element of problematizing and encourage technical literacies for all students. In addition, many technology environments do require algorithmic approaches, pattern recognition and problem-based thinking.

Social Studies and Individuals and Societies courses have an opportunity for linking CT in topics, such as those within the DP Information Technology in a Global Society course. Topics in this course could provide insight into other DP subjects and covers aspects such as digital and social media within society, as vital social movements and dynamics of change (e.g., the rise of the Internet, the dot com era, design and maker culture). Students could consider parallels between the industrial revolution and the information age, where the power of computation has dramatically boosted the economy and changed lifestyles and the nature of work. They could also try to understand the rise of automation and machine learning as new movements, as well as the role of social media and advertising on the internet. "Fake news" and the need for critical thinking could further engage such discussions, as simply understanding some of these ideas could be critical to students' own identity formation, schooling decisions, and engagement in CT and DT.

Another strategy, for any given course, could be to consider design and computation within the landscape of professional practice in the course disciplines (e.g., mathematics, engineering, chemistry). Looking to IB's *Career Programme* and relevant DP courses (e.g., Design Technology, Computer Science, and Information Technology in a Global Society) could be a fruitful strategy for alignment. Teachers and course designers could identify where design is happening and how computation, technology and media are playing a role in the field, adding a level of personal and social relevancy of the course, as well as vital context, meaning and purpose for students. Future versions of the course guide could help provide such a context for the topic of study, which could promote interdisciplinarity and give a sense of direction to instructors and programme coordinators. The Teacher Support Materials can then provide guidance about how to include such career connections, foster interdisciplinarity, and support a competency-centred approach.

Section 3

What are IB Teachers' Understanding and Implementation of Design and Computational Thinking?

Programme Coordinator and Teacher Surveys

Section 3. What are IB Teachers' Understandings and Implementation of Design and Computational Thinking?

Key Take-aways

- Teachers from all three programmes report a high level of familiarity with and understanding of DT and CT, and how it can fit within their courses.
- Project-based work is commonly cited as a strategy, where students must engage in creative problem solving.
- The dimensions of DT and CT most commonly addressed by teachers are those that are common to inquiry and project-based curriculum, like creativity, collaboration and problem solving.
- Some teachers expressed limited understandings and lack of confidence in how to integrate DT and CT.

To address the question of how IB teachers understand DT and CT, and how they are implementing those competencies into their courses, we developed a survey in which we asked structured questions (i.e., close-ended responses) about (1) their level of understanding of DT and CT definitions, (2) their confidence in how well they are integrating CT and DT into their courses, and (3) the degree to which they have succeeded in integrating DT and CT. We also posed open ended questions about *how* they are integrating DT and CT, as well as any obstacles they perceive in adding DT and CT into their courses.

Method (survey of IB teachers)

Surveys comprised four main parts:

A. **You and Your School,** in which teachers provide information about their current position, level of experience, what course they teach, and how many students are in their classroom;
B. **Design Thinking and Computational Thinking Within Your Classroom**, in which they rate their level of understanding of DT and CT, and the importance of these topics as 21st century skills, and as topics for instruction in their courses;
C. **How You Integrate Computational Thinking and Design Thinking in Your Teaching**, in which they rate their level of emphasis of DT and CT, the amount of their course that makes connections to them, and whether they feel that the course is successful in helping students develop these competencies; and
D. **How Design and Computational Thinking are Integrated Across IB Programmes**. In the fourth section, teachers responded to open ended questions about how they integrate CT and DT, how their courses could be improved in regard to CT and DT integration, and what obstacles they may face.

The final versions of all three surveys (DP, MYP and PYP) are provided in Appendix E. A full set of survey responses is available from the IB research office. Surveys were provided in all three IB languages; French, Spanish and English per IB's explicit process regarding this.

We begin with an examination of teachers' responses to structured questions about their level of understanding, to reveal basic levels of understandings and look for patterns across several variables (course topics, teachers' years of experience, types of school, and geographical regions). We also examine teachers' beliefs about the importance of DT and CT for 21st century learners, and whether they feel their school prioritizes DT and CT.

A subsequent qualitative analysis examines teachers' responses to the open-ended questions, to inform our understanding of how CT and DT are embedded within their courses. For each programme, we read through all qualitative items submitted by teachers for each course, using an open coding method to capture common themes. Our method was to first read the entire corpus, including 3355 records for each of the 2 items coded (6,710 total items), selecting a sample of representative items for an open coding for "ideas". An idea was defined as some relevant example or instantiation of the teachers' responses. For example, in response to the item "Please describe one way in which you have successfully integrated design thinking for your students.", a teacher might reply that they thought they could add more open-ended problems. When coding the selected sample, this would constitute a distinct idea, and be coded as "add open ended problems". An item was selected for coding if it was well formed, included either a distinct new idea or exemplified an existing idea within the codes. In this way, a represented sample was prepared for open coding. The sample comprised 180 responses for the DP survey, 126 items selected from the MYP survey, and 118 items selected from the PYP survey. English, Spanish and French language items were read for content, and a representative number of items from each was included in our sample.

Participants

For the DP, we received 785 complete or partial responses to the survey, which was sent to 1024 school coordinators to be forwarded to teachers of the courses we were auditing (Physics, Chemistry, Mathematics, Computer Science, Geography, Design Technology]. Of the respondents, 92% (719) were teachers and 8% (66) were coordinators. Figure 6 shows the breakdown of teacher respondents, per course, with the highest level of responses received from mathematics, chemistry and physics teachers.

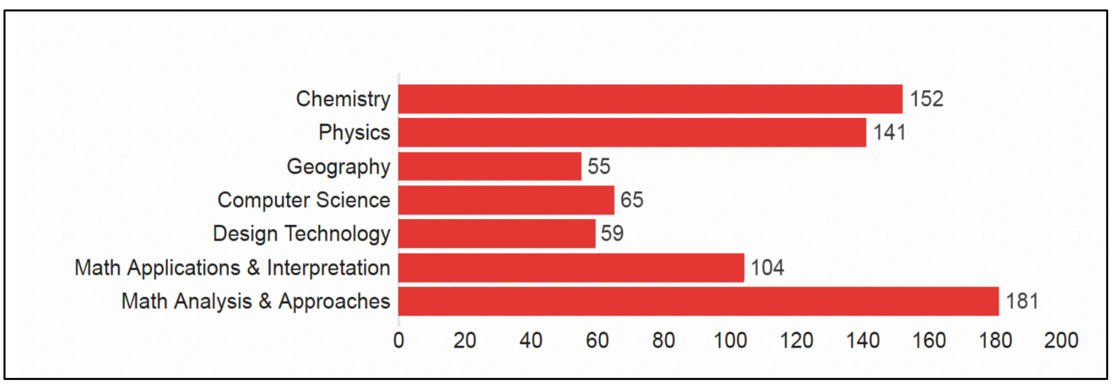


Figure 6. Number of DP teachers responding from each of the audited courses.

The MYP survey was sent to 192 school coordinators, who forwarded it to their teachers. We received 298 complete or partial responses to the survey, 91% of which (272) were teachers and 9% (26) were coordinators. MY teachers selected from one of four subject groups: Design, Sciences, Individuals and Society, and Mathematics, with fairly equal representation from all four (Figure 7).

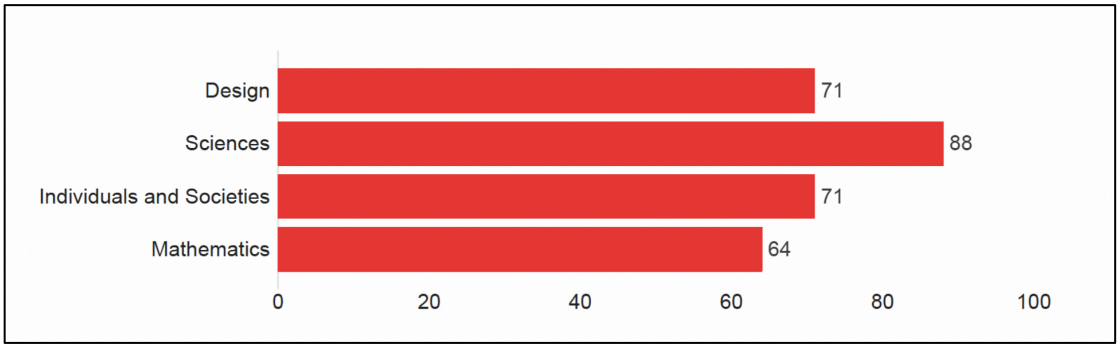


Figure 7. Number of MYP teachers responding from each of subject groups.

The PYP survey was sent to 581 coordinators, who forwarded it to their teachers. We received 513 complete or partial responses to the survey, 83% of which (425) were teachers and 17% (88) were coordinators. PYP teachers were asked to select one of five age groups (3-4 years, 5-6 years, 7-8 years, 9-10 years, and 11-12 years), with a larger number of respondents in the middle three categories, but a fair representation from all (see Figure 8).

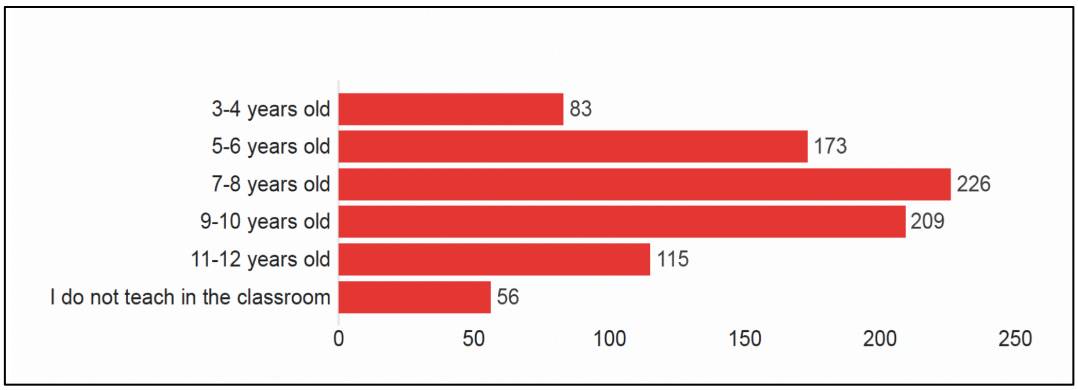


Figure 8. Number of PYP teachers responding from each of subject groups.

Teachers' understanding of DT and CT

We began with a close examination of teachers' self-reported understanding of DT and CT. Survey respondents were asked to rate the statement "*I have a strong understanding of CT/DT*" on a scale from strongly agree" to "strongly disagree." Figures 9 and 10 show the summary of teachers' responses for all three programs. The figures make it clear that IB teachers, on the whole, feel quite strongly that they do understand both design thinking and computational thinking. In fact, very few teachers replied with a lower score than "somewhat agree" and a large majority voted either "agree" or "strongly agree". This trend is consistent across all three programmes, and for both DT and CT. It is worth noting that PYP teachers scored no lower on this measure than their peers in other programmes. While it is important to note that these are self-reported understandings, and respondents may *believe* they have stronger understandings than they actually do (i.e., there may be more to DT or CT than they suspect). Still, it would be difficult to objectively measure such understandings, especially for constructs that are still in the early stages of being operationalized. These reported understandings should be seen as a positive outcome and certainly indicate a positive attitude of teachers regarding CT and DT.

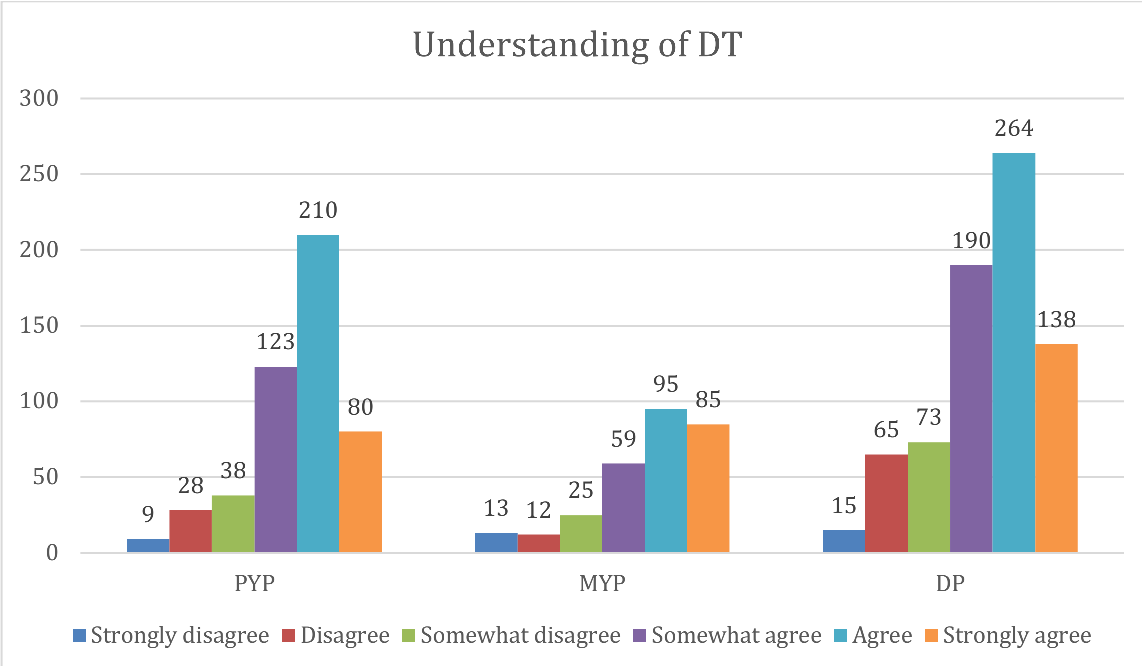


Figure 9. Teachers' agreement with the statement: "I have a strong understanding of DT

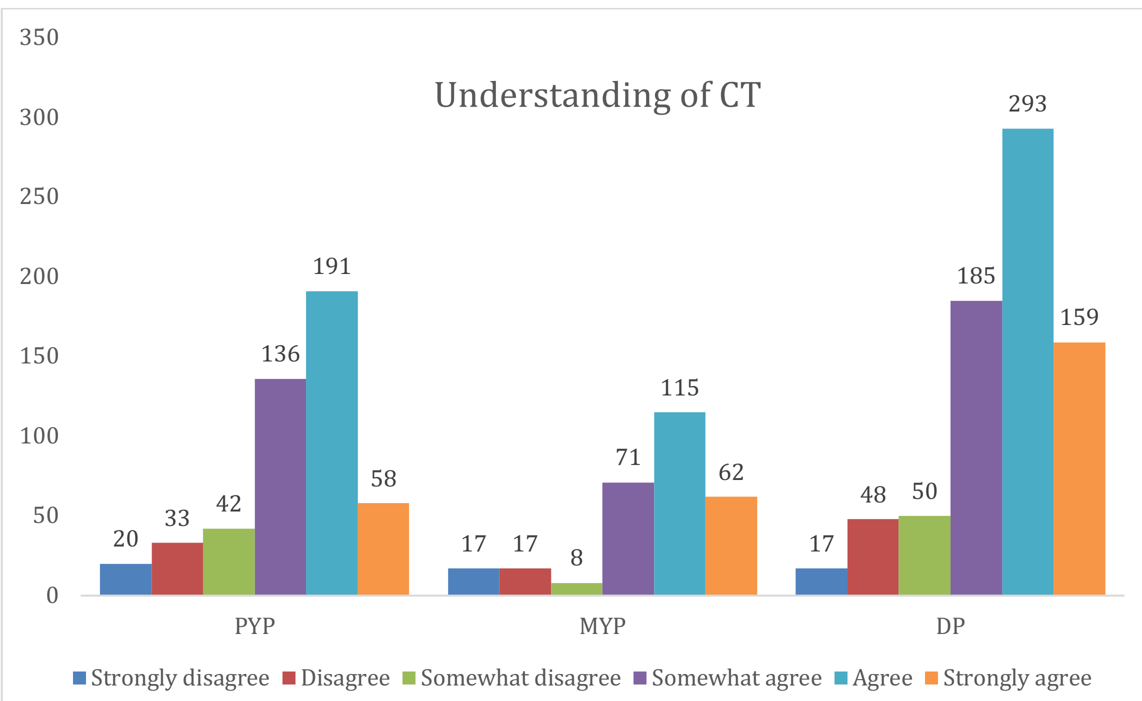


Figure 10. Teachers' agreement with the statement: "I have a strong understanding of CT

Next, we asked whether teachers from different course topics or student age group (in the case of PYP) varied in their understandings of DT and CT. Figures 11 and 12 show patterns of agreement by the DP teachers from the six different audited courses, revealing some interesting differences following expected disciplinary boundaries. Clearly, Design Technology teachers have the highest confidence in their understandings of DT, and Computer Science teachers have the highest confidence in their understandings of CT. Beyond those clear patterns, there may be other patterns within specific courses worth noting (e.g., the lower scores on CT by Geography teachers), but overall these scores reflect the same overall pattern of high confidence in understanding.

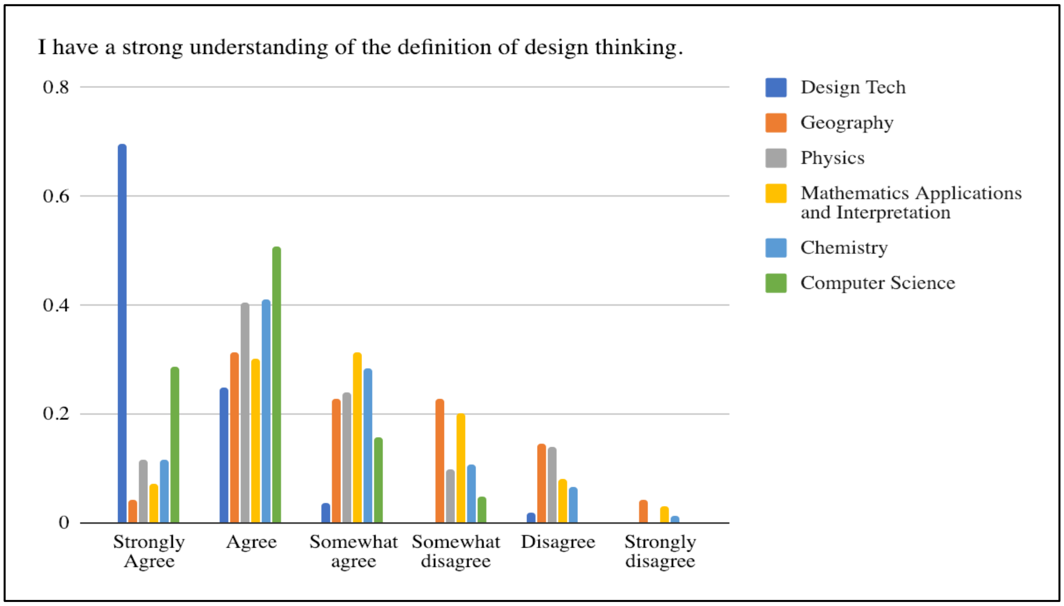


Figure 11. DP teachers' understanding of DT by course

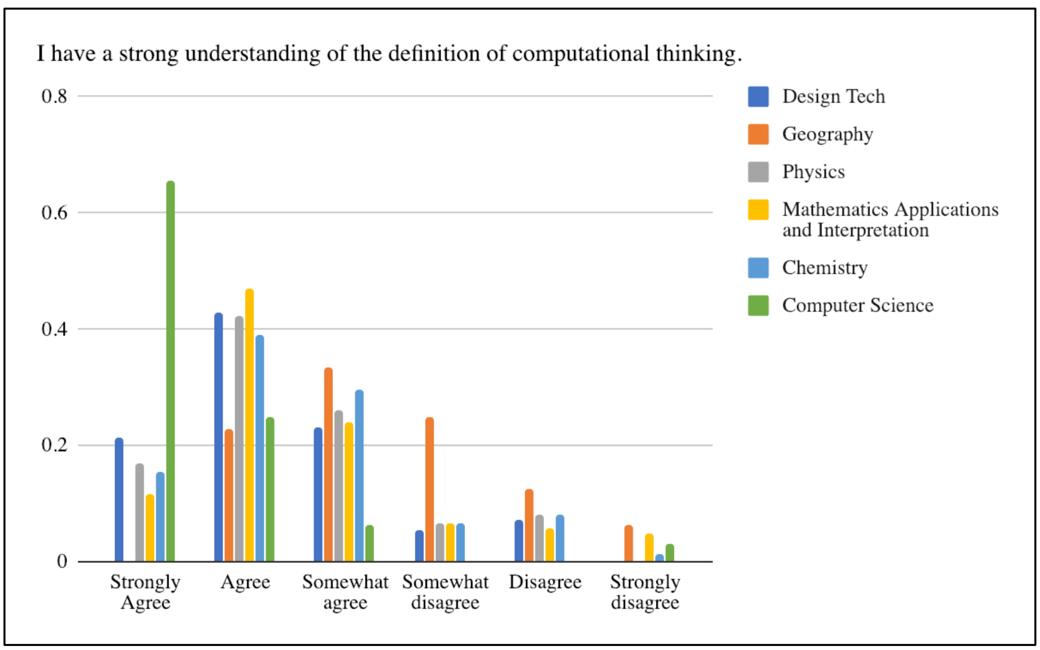


Figure 12. DP teachers' understanding of CT by course

Figures 13 and 14 show the MYP teachers split according to courses taught, showing that Design teachers have a much higher self-appraisal of understandings for both DT and CT. For PYP, there were no topic areas to contrast, as teachers instead differ on student age levels. But these were not unique (i.e., teachers could select multiple age groups), so we did not perform this split for PYP.

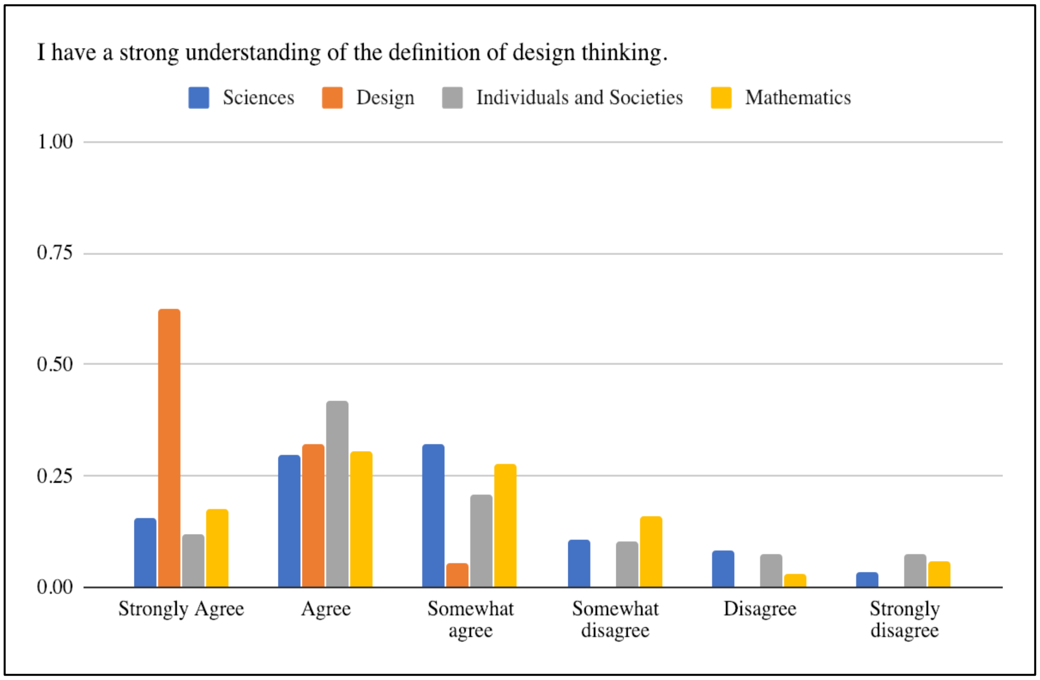


Figure 13. MYP teachers' understanding of DT by course

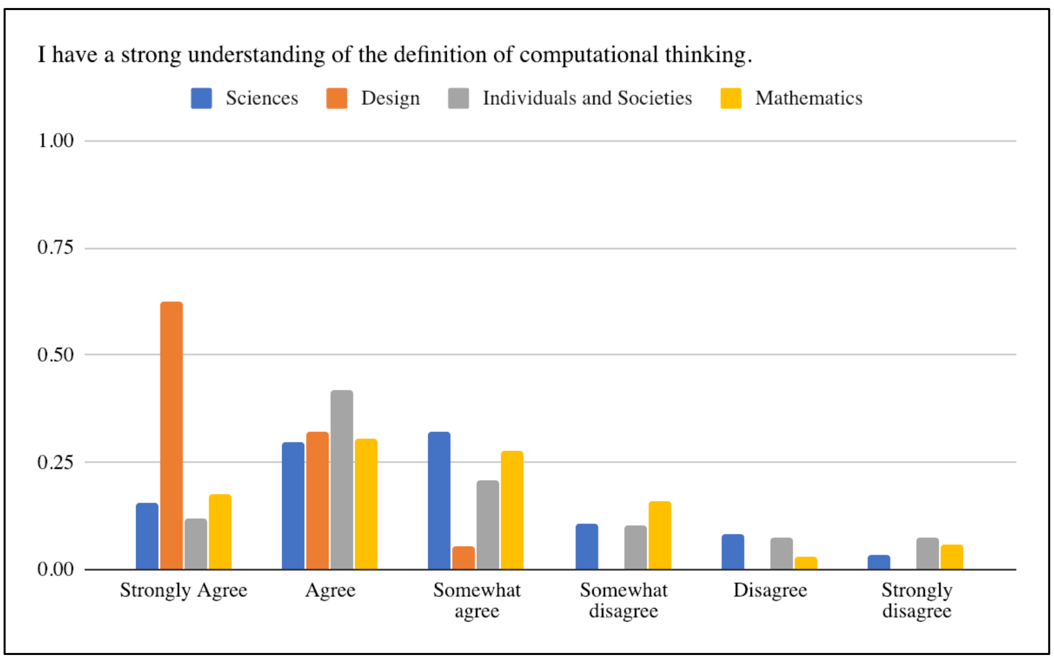


Figure 14. MYP teachers' understanding of CT by course

We also looked for any meaningful patterns of variation in teachers' level of understanding when they were compared across categories of (1) teaching experience level, (2) type of school, or (3)

Human Development Index (HDI). In general, we did not find substantive differences warranting the inclusion of graphs here. Teachers' understanding of CT and DT does not vary considerably across *levels of teacher experience* (0-3 years, 4- 10 years, more than 10 years, "programme coordinator"), *school types* (Charter, Private, State, and State subsidized) or Human Development Index (HDI -- low, medium and high countries). While not sufficiently important to warrant inclusion in this main report, there are some interesting patterns in the graphs, so we provide them in Appendix D. Note that some patterns are likely artifactual, based on the small number of respondents for certain categories. Hence, we do not recommend drawing any strong conclusions from specific patterns of means in Appendix D.

Teachers' opinions about the importance of DT and CT

Two items that reveal how IB teachers feel about DT and CT are as follows: (1) *DT/CT is important for 21st century learners*, and (2) *DT/CT is a current priority in my school*, both of which were again rated from "Strongly disagree" to "strongly agree". Figures 15, 16 and 17 show these results for the three programmes, respectively revealing an interesting contrast: Teachers in all three programmes overwhelmingly agree that DT and CT are important 21st century competencies (blue and red bars in each Figure), but are far less convinced that their schools share this sense of importance (green and purple bars).

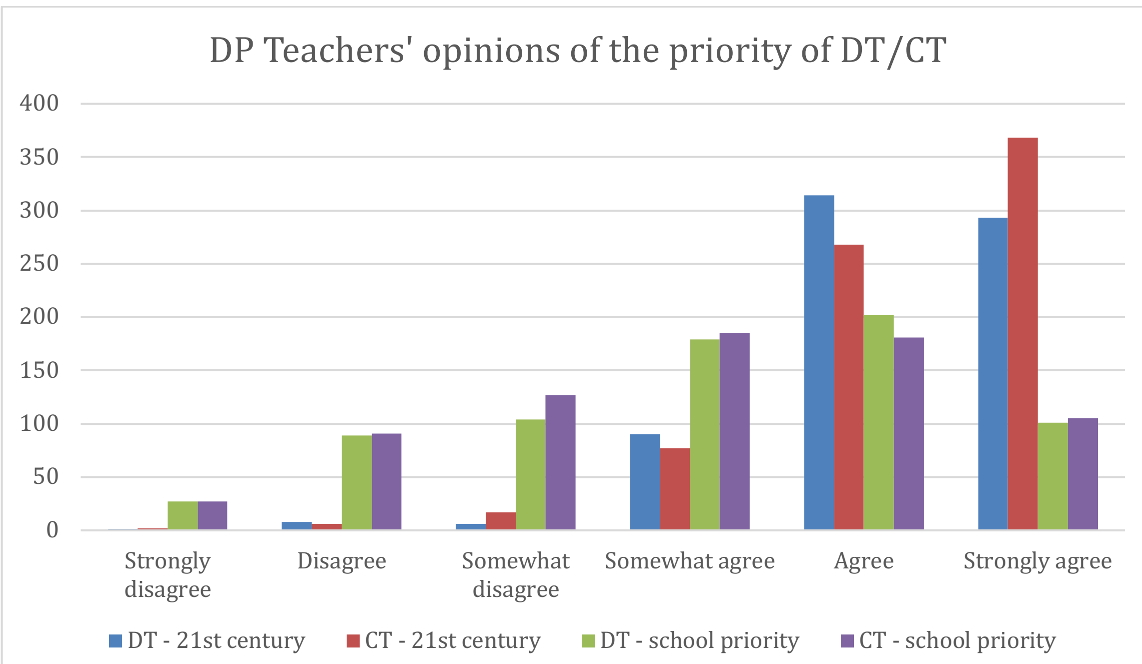


Figure 15. DP teachers' opinions about the importance of DT and CT

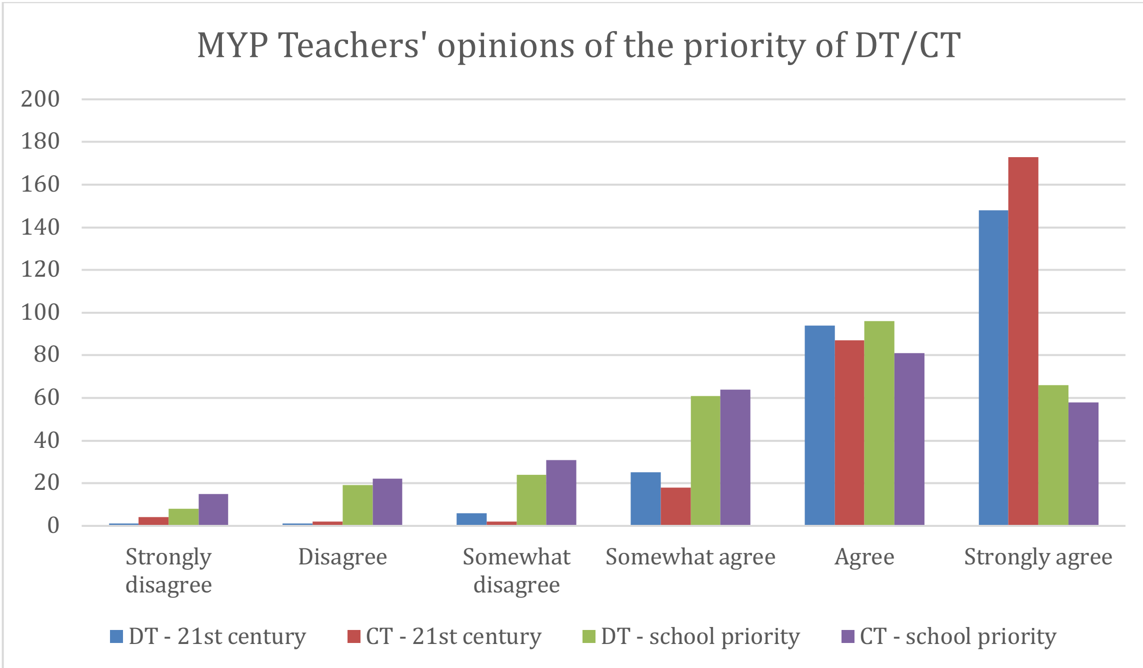


Figure 16. MYP teachers' opinions about the importance of DT and CT

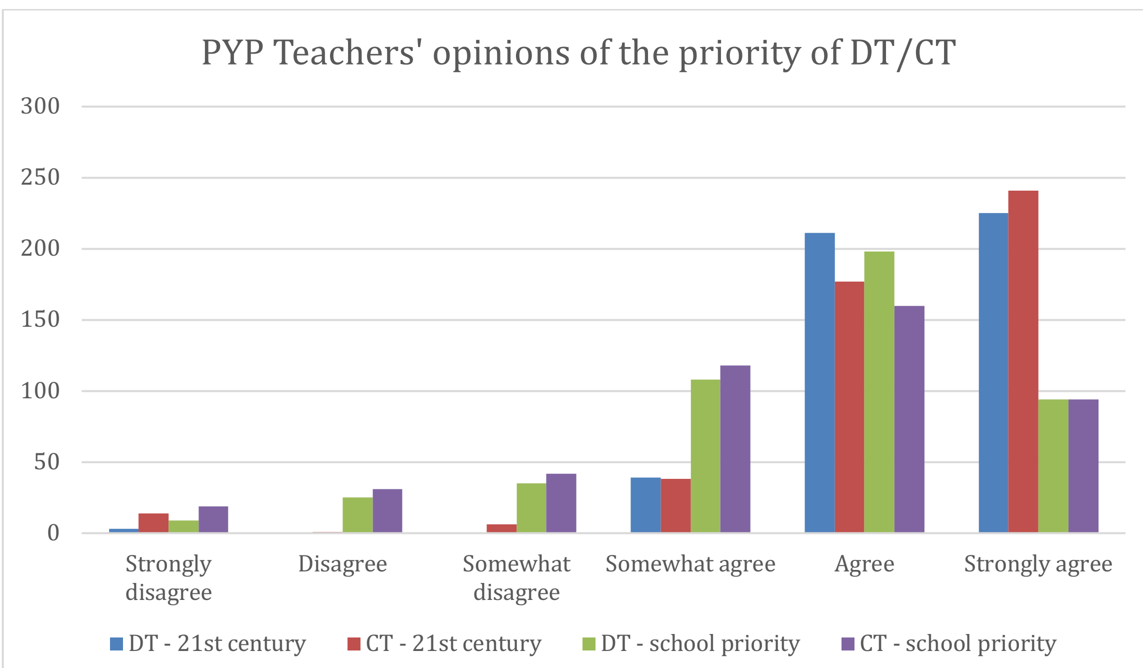


Figure 17. PYP teachers' opinions about the importance of DT and CT

Teachers' strategies and approaches

Next, we examine qualitative patterns within teachers' replies to open ended items, in order to shed light on how they are adding CT and DT into their courses, and how they think they could improve their treatment of these topics. More than 1000 DP teachers responded to our survey, with approximately 65% responding to the open-ended items. More than 450 MYP teachers responded to our survey, with approximately 75% responding to the open-ended items. More than 1000 PYP teachers responded to our survey, with approximately 50% responding to the open-ended items -- providing a good sampling of the major ideas held by teachers. These response rates meant that we had hundreds of replies for each survey, and typically dozens for any particular course audited (or age band, in the case of PYP). Thus, we can have confidence that the ideas and approaches represented in these responses reflect a fairly broad sampling of the major ideas held by teachers.

To address the research question, we coded teachers' responses to two questions: (1) Describe one way you have successfully integrated CT/DT for your students, and (2) Describe an example of how you could improve the use of CT/DT in your teaching. Because these questions both address teachers' pedagogical ideas and practices, with regard to their current courses, we combine them in our coding and discussion. For each programme, we read through all qualitative items submitted by teachers, using an open coding method to capture common themes. English, Spanish and French language items were read for content, and a representative number of items from each was included in our sample. Our method, described above, prepared a sample of teacher responses from the three surveys, for the open-ended items regarding "strategies used for integrating DT/CT" and "obstacles for succeeding with the integration of DT/CT". These samples were selected to represent the spectrum of most common responses. For example, when a certain strategy was described by many teachers, only a few items were selected that represented that response. The goal of this sampling was to create a representative view of the hundreds of responses, so that common ideas (strategies or obstacles) could be coded and synthesized. Table 10 shows a summary of the strategies, organized by programme, which are detailed in the ensuing sections.

Table 10. Summary of DT and CT integration strategies across the programmes.

	DP	**MYP**	**PYP**
Design Thinking	(1) the use of open ended and student-centered problems (2) integration of DT (3) the role of internal assessments (4) the discipline specific nature of design (5) structural issues of time and resource allocation.	1) the use of authentic, open-ended problems (2) the use of iterative cycles of revision (3) the explicit inclusion and assessment of DT within the curriculum (4) collaborative projects (5) supporting creativity (6) the discipline specific nature of design.	(1) play and creativity (2) open ended problems (3) collaboration or group work (4) integration of topics across disciplines (6) student-selected problems.

Computational Thinking	1) inclusion of technology-based activities; (2) integrating computation and numerical problem solving, (3) use of data management in projects and problem solving, (4) scientific method and problem solving, (5) emphasizing collaboration, and (6) multidisciplinary partnerships with DP Design.	(1) connections to design; (2) general inclusion of technology; (3) integrating programmable hardware technologies; (4) use of programming environments; (5) focus on algorithms; (6) working with data.	(1) finding patterns, (2) breaking problems into smaller parts, (3) the use of puzzles and problems, (4) math and number play, and (5) adding technology. (6) computer games, (7) use of concept maps and flow charts, (8) robotics, and computer programming.

The Diploma Programme

How DP teachers are integrating Design Thinking

With regard to the integration of Design Thinking, DP teachers shared a range of interesting ideas and approaches. While these ideas varied expectedly across the course topics, here we synthesize them, drawing examples to reflect the discipline specific elements. The major types of ideas we identified were concerned with (1) the use of open ended and student-centered problems, (2) the close integration of DT, (3) the role of internal assessments, (4) the discipline specific nature of design, and (5) structural issues of time and resource allocation. While these latter ideas are treated more directly in Research Question 4 (“Key challenges for the IB”) – they are included here because teachers often mention this even when asked directly how they are currently, or potentially integrating DT. While there were other, more nuanced ideas present within the responses, these provide a realistic representation of the predominant ideas within teachers’ responses to the two open-ended items

(1) The use of open-ended problems and student-centred learning approaches.

One idea that was commonly expressed regarding the integration of DT was teacher’s use of open-ended problems. Respondents felt this approach engaged students in many of the dimensions of our working definition (teachers were provided this definition within the survey, in advance of responding to these questions). Some teachers described specific activities in which they felt DT was well represented. For example, a DP Chemistry teacher said, "*In Option D, Medical Chemistry students worked on designing a framework on developing a more sustainable world using principles of green chemistry (using catalyst, alternative solvents etc.) and how the problems of 21st century can be resolved.*" Another chemistry teacher offered, "*Giving molecular models to students to create their* *own design of new allotropes to Carbon…* Investigating limiting reagent concept by lab activity (precipitation reactions). And using Simulations in teaching (pHet simulations)".

(2) The close integration of DT within instructional activities.

Other teachers gave specific examples of activities in which they engage design thinking, such as this DP Geography teacher who replied: "*When deconstructing management strategies (e.g. river flooding/renewable energy) to look at how it is constructed, who it impacts and then evaluate its overall effectiveness.*" Similarly, a DP Design teacher described how they addressed the important dimension of stakeholder empathy: "*Stakeholders diverse views on a situation, investigating the situation, thinking of solutions, trying to create empathy with the situation, evaluating the success of solutions of a case study... but no further*". Other teachers recognized the importance of fieldwork activities: *"Students have to create models to represent the data they find on their fieldwork investigation for their Internal Assessment (IA) and we discuss at length different ways to draw in an audience through the design of the data display methodology."* In computer science, some teachers replied that they employ a design method to think about software creation, including prototyping and iterative refinements. This entails connections to real world problems, as well as collaboration and creativity. For example, one computer science teacher said, *"We teach the iterative process of design thinking and prototyping. Students have to develop write ups outlining their design, planning, prototype and then actual solution. This is then extended to the IA."*

(3) The role of internal assessments.

Another idea expressed by DP teachers was that students' preparations for the Internal Assessments was highly engaging of DT. One DP Chemistry teacher said, *"Design thinking has been used during my chemistry classes during preparations for Internal Assessment tasks. It resulted in good marks received for innovative and well-prepared individual investigations."* A Computer science teacher said "*The design thinking is applicable directly to the internal assessment, but is not reflected explicitly in the CS curriculum.* And a DP Mathematics teacher replied, *"The writing of the IA is essentially a design thinking process to begin with. Then computational thinking is a part of the IA."* Many teachers in Chemistry and Physics expressed that the labs and internal assessments address DT, specifically (e.g., a design lab), and that experimentation includes an element of design thinking. For example, one DP chemistry teacher said, *"The scientific methodology and design thinking are strongly related so pretty much any design experiment uses design thinking."*

(4) The discipline specific nature of DT.

DP teachers often expressed ideas relating to their particular discipline – sometimes offering how discipline specific aspects reinforce design thinking, while other times suggesting that their course might not be a good fit for integrating such competencies. Not surprisingly, DP Design Technology teachers commonly felt that DT is central to their discipline, and that students come to achieve this competency – solely by virtue of their participation in the course. For example, one teacher said, *"Design Thinking is a fundamental part of the DP DT course. Allowing students to understanding the design cycle and experiment with design concepts and iterative them allows for problem solving and solutions being considered suitable to fulfill a brief."* However, there were Design technology teachers who felt a lack of emphasis on certain parts of DT, such as one who said, "*The IA requires the students to use the design thinking methodology, but the course doesn't allow time for the pupils to practice the art of empathetic design or ideation as the time it takes to teach the theory content impinges on it .*" Other Design technology teachers replied that they do engage those same aspects, directly, for example: *"The way I have integrated it is through design challenges emphasizing empathy* *and empathic design. Also trying to connect design thinking within the design project. However, some of the Design project requirements detract from the design thinking method."*

A few teachers felt that DT falls completely outside their province, such as the DP physics who said, "I don't integrate it. I teach Physics, please stop this and let teachers teach rather than telling us how to teach, we don't need another fad… just adds more to a course that is way too content heavy for the time we have. Let us teach, stop re-inventing the wheel." For such teachers, it would appear that a larger conversation may be required, for them to understand that one important goal of any DP course is to foster certain forms of thinking and critical competency. The teacher quoted here reported only 2.5 years' experience, suggesting that they are a newer teacher who could likely be helped to expand on their pedagogical perspectives and require additional support with regards to how content matter relates to competencies like computational and design thinking. Other teachers appeared sympathetic to the idea that DT could be nurtured even in situations that not explicitly focused on design, such as this DP Geography teacher: "I think we do this a lot without necessarily being aware of it. For example, students completing IAs (in both ESS and Geography) take a very independent path which often encounters problems to be solved and modifications to be applied."

(5) Structural issues of time and resource allocation.

Finally, many teachers acknowledged their limited ability to integrate DT, as reflected in their replies to the more quantitative items analyzed above. Several teachers recognized that solving ill-structured problems would provide a good opportunity for the integration of DT, but that they did not have enough time or support to integrate such activities. For example, this DP Geography teacher replied, *"decision-making and problem-solving exercises. These need to part of IB summative examinations or forget it."* Other teachers acknowledged that there is no explicit treatment of DT within their course: *"not possible due to time constraints in a deep and broad curriculum with conceptual learning and nexus thinking to integrate, teach, assess"* Others were more succinct: "*There is very little opportunity for this in the current course."* Finally, some teachers acknowledge that they have not succeeded in this goal of integrating DT for example, a DP mathematics teacher who replied, "I don't believe that I have successfully integrated design thinking for my DP students."

How DP teachers are integrating Computational Thinking

With regard to integrating computational thinking, DP teachers expressed many of the same ideas as they provided for integrating design thinking (reviewed above). For example, one computer science teacher noted that CT is relevant to the internal assessments: *"On the IA and during model analysis, students must use computational thinking skills to correctly interpret what they see. Furthermore, students use Spearman's Rank to demonstrate the strength of the correlation between variables".* Instructors offered fewer specific illustrations and activities than they did for DT, with many appealing to the more general computational nature of problem solving. For example, one DP Chemistry teacher said, "*There are many examples of this; anywhere where a standard way can be used to think the way through a problem.*" Some Computer Science teachers felt this was addressed intrinsically through their very discipline, without need of any further consideration, for example, "*There is no way to teach Computer Science (Option D: Object-oriented programming (OOP)), without integrating computational thinking in the classes*". Another computer science teacher said, "*Programming is all about computational thinking.... Making the students solve tricky problems helped me in integrating computational thinking*". DP Design technology teachers appeared to make heavy use of computational projects (i.e., as part of design assignments, such as one who responded: "*Various coding projects at almost every year level.*" Other teachers appealed to certain aspects of their respective disciplines, such as this DP chemistry teacher *"Computational thinking was useful in* *generalizing the trends into rules, especially for trends of chemical bonding strength, intermolecular interactions and physical properties of substances."*

As with DT, some teachers did not see elements of CT appearing in their teaching - perhaps because they were fixed on the necessity to include computers, but also because of a lack of explicit requirements or guidance. For example, when replying about how they integrate CT, one DP Design Technology teacher said, *"Very little. If it was built into the curriculum, we would do more."* A DP Chemistry teacher said, *"Computational Thinking is handled by ICT professionals."* To some degree, all of the ideas listed for DT above were also present in teacher responses about CT. To avoid redundancy, we will not repeat them here (examples can be seen in the sample provided in Appendix E) and instead present six additional ideas that were specific to DP teachers' integration of CT, including: (1) inclusion of technology-based activities; (2) integrating computation and numerical problem solving, (3) use of data management in projects and problem solving, (4) scientific method and problem solving, (5) emphasizing collaboration, and (6) Multidisciplinary partnerships with DP Design.

(1) Inclusion of technology-based activities.

One of the main ideas expressed by DP teachers, with varying levels of sophistication, was that students' CT could be engaged through the addition of technology devices, tools, materials and activities. While some teachers were quite opaque in terms of how this could engage CT (e.g., a Chemistry teacher who said, *"Computational thinking is incorporated by assigning work that requires the use of software in the completion of the task and cannot be completed effectively without the use of computers*"), others revealed more detail about how this would complement their specific courses and discipline. A DP Math teacher replied, *"In many cases, repetitive math problems can be coded into Excel. I have my students do this. If they can teach a computer to find eigenvalues and eigenvectors based off of an initial matrix, they really understand the process."* Another DP teacher (also in mathematics) observed that technology is a prerequisite for some activities, and that the resources must be in place before they can be deeply integrated: *"Once you have the technology in place, it is time to begin integrating computational thinking into lesson planning. You should begin to consider different ways your students can work on problem-solving while utilizing technology".*

(2) Integrating computation and numerical problem solving.

One recurring idea within DP teachers' response to these items was that CT is engaged through numerical problem-solving techniques. One DP mathematics teacher observed, *"We have integrated CT in a topic called numerical techniques. For this topic, students adopted computational technique to calculate the larger values in the iteration technique."* A physics teacher described the following approaches: *"Development of time and data management strategies for IAs and EEs. Allowing pupils to plan and execute using holistic view with specific skills applied selectively and appropriately."* While such techniques may be more relevant only to certain disciplines, they are clearly of value in the 21st century workplace, where data-driven decision making has become the accepted norm. The methods would be relevant to areas of marketing and learning analytics, as well as politics and economics. They are closely related to the next strategy, relating to data management, although we treat them separately here as they address slightly different aspects of CT.

(3) Use of data management in projects and problem solving.

This strategy has to do with helping students understand the nature of structured data and how it can be used to address problems (problem solving is a key aspect of our working definitions, of both DT and CT). Many teachers, in the sciences as well as Geography and Design Tech, see the value of engaging students in reasoning with data. One DP physics teacher offered this idea, of having students inform their designs with data (an approach that would seem well suited to design courses as well, or any design project): *"Computational thinking requires looking at data and adjusting a design or a variable. This is done in the design labs with the students. They analyze data and then optimize their designs."* Another physics teacher responded, *"In IA, data analysis part, solving open ended problems. Using simulations and databases (from NASA) for students to collect data and make a conclusion".* The availability of public, open data sets has offered new opportunities for teachers to have students engage with a wide range of questions relating to humans and their environment, economics and the marketplace, and any number of large scientific projects that publish open datasets. DP Teachers are beginning to utilize those data as resources for projects and problem-solving tasks, which serves to engage CT.

(4) Scientific method and problem solving.

Some teachers saw aspects of CT in the scientific process of testing hypotheses, or other aspects relating to the nature of science. One teacher seems to value hypothesis testing, which involves finding correlation with data: *"The parts of the syllabus that are open to calculations of sorts - correlations, testing hypotheses and then rethinking the hypotheses and finding new matters to correlate".* Another teacher offers a similar emphasis, connecting hypothesis testing with investigations: *"Introduce more hypothesis testing and planning of investigations. I would also like to see more decision-making exercise which culminate in a final creative element, through which design thinking can be investigated".* While these scientific methods are not directly connected to specific forms of CT, they do align with the problem-oriented aspects of our working definition, suggest pathways for introducing CT within such problems. Another teacher observed the value of introducing "NOS" (Nature of Science) in order to build awareness of what scientists do, and current problems: *"By discussing more and more NOS questions to make them aware of the contributions of the scientists and also by discussing the possible solutions of the existing problems".*

(5) Adding collaboration.

Interestingly, many DP teachers saw collaboration as being important to their inclusion of CT. While collaboration was not an explicit element of our working definitions, it seems to be important to many teachers' understandings of problem solving and inquiry, which they see as the locus for CT. One math teacher observed, *"Perhaps a collaborative IA in year12 as a means of preparing for individual IAs in year13, time depending".* Likewise, a physics teacher offered this idea for how CT could be better supported: *"Use of more collaborative problem-solving approaches within each class to solve practical problems in their own environment. It's a good way to flip the classroom and have them apply their learning in a safe environment".* Finally, a DP design tech teacher summed up this perspective, that collaborative inquiry projects generally could support CT: *"Through interdisciplinary collaborative projects, resources, field trips and/or specifically focused projects. (Perhaps.)"*

(6) Multidisciplinary partnership with DP Design.

A final interesting theme in this analysis was the idea that CT could be included in DP courses through partnerships with the Design Tech course. In particular, it was felt by teachers that such an approach could be added to the IAs. One physics teacher suggested, *"We should collaborate with Design technology department to deepen the understanding of concepts which could be shown through the models made in design studio and explain the design that they have adopted based on the theory studied in classes".* Teachers suggested this could be done by maintaining separate IAs for the participating courses: *"Joint IA work with Design Technology where the final product is a physical one* *and each student applies different skills (cooperative work). The produced IA are separate, with a shared target. We would need a better outline from the IB on what they expect in IAs in regard to this*".

The Middle Years Programme

How MYP teachers are integrating Design Thinking

With regard to the integration of Design Thinking, MYP teachers again shared a range of interesting ideas and approaches, which were similar to those expressed by DP teachers. While the ideas varied expectedly across the course topics (i.e., Design teachers did have more focused observations and approaches than those in social studies), we again synthesize them, drawing examples to reflect the discipline specific elements. The major types of ideas we identified were concerned with (1) the use of authentic, open-ended problems, (2) the use of iterative cycles of revision, (3) the explicit inclusion and assessment of DT within the curriculum, (4) use of collaborative projects, (5) supporting creativity, and (6) the discipline specific nature of design. While there were other, more nuanced ideas present within the responses, these provide a realistic representation of the predominant ideas within teachers' responses to the two open-ended items. A sample of responses, includes those quoted below, is provided in Appendix E.

(1) Use of authentic, open-ended problems.

Many teachers in the MYP recognize the importance of problem solving as a means of engaging DT. Indeed, the emphasis on open ended problems is central to any definition of design, as it allows for collaboration, creativity and iterative improvement of ideas. Many courses within the MYP embrace a commitment to design and open-ended problems, and this is reflected within teacher responses across the curriculum. One teacher of MYP Individuals and Society described this approach through the "*Integration of designing products that can be useful for eco concerns*". Similarly, an MYP mathematics teacher describes how "*Design thinking can be improved by applying mathematics in world contexts. Solutions to real world issues can be discussed by proposing plausible designs of products, systems etc. that incorporate certain mathematics concepts*". Design of products appears to be a common strategy, as described by one math teacher: "*When I was teaching the circles. I asked them to make the twitter logo using the circles. They were amazed at how can it be possible designing a logo (bird) using just circles*". One MYP science teacher employs the following task, "*designing aluminium boats to test Newton's laws, displacement and buoyancy*". Thus, MYP teachers seem to have recognized the potential for such projects to engage students not only in DT but also in the constructive application of concepts and processes, which can help solidify their understandings. Another math teacher expressed this general idea, as "*by integrating more project-based learning and dividing the project in different steps and algorithms*".

(2) Use of iterative cycles of revision.

While this theme was found most often in the replies of MYP Design teachers, it represents another vital dimension of DT that is relevant to any real-world design project. The parentheses in one design teacher's reply illustrates an understanding of how iteration is important: "*All my MYP Design Unit are centered around Design thinking, from Gardening (which allows multiple iterations), to woodwork or 3D-printing*". Another makes the point even more explicitly: "*Include more iterations to show how things can continuously be improved upon in order to achieve a better outcome. Sometimes we are constricted by internal deadlines that don't allow for extending the development phase.*" A math teacher describes how iteration is used to engage students in evaluating designs: "*Creating iterations of the design of a new school facility, based on real life application.* The fact that revisions require designers to evaluate the previous version (i.e., in order to inform the next) offers great pedagogical value, as they must consider ways of evaluating the design, which can entail computational thinking.

(3) Explicit inclusion and assessment of DT.

Some MYP teachers are quite deliberate about including and assessing design thinking. One math teacher replied, "when there are activities or assessments, I integrate the elements and process of design thinking specifically when they have to define a problem, go through an experimental phase and eventually work on the product or output." Another teacher offered, "I integrate the elements and process of design thinking specifically when they have to define a problem". In part this is likely due to a sense of responsibility to include DT, as instilled by MYP teacher materials. There is clearly a program-wide commitment to design, such that teachers do consider it an important transdisciplinary connection. Other teachers recognize a special form of knowledge associated with design, which they seek to engage. For example, this science teacher suggested, "By giving projects to students which involves them using design knowledge to design "Green City"- that uses all environmentally friendly components".

(4) Use of collaborative projects.

Collaboration is recognized as one dimension of design thinking within our working definition (Section 1). While one could surely engage in design thinking without collaborating, most research studies emphasize the value of having multiple voices and active discourse around the ideas, such as derives from collaborative problem solving. One mathematics teacher observed, *"Our statistics unit required students to collaborate on and generate methods for problem solving to complete their assigned work".* A science teacher describes employing *"Group projects in which students have to build a model to show how they would address the limitations of a human illness or disease"*. Thus, collaboration is seen as being sufficiently important to the engagement of DT that teachers are citing it as a strategy.

(5) Supporting creativity.

Another dimension of our working definition that was shared amongst some MYP teachers is the value of creativity. While it is possible that one could engage in creative thinking without performing any kind of design thinking, it is unlikely that the inverse could be true. In other words, creativity is likely an intrinsic part of any design process. A number of teachers simply stated that they used tasks that engaged students' creativity, with the tacit reasoning that this should engage students in DT. For example, a design teacher replied, *"I have asked them to design and create an Augmented Reality app that worked with paintings the students had previously created".* Similarly, an Individuals and Society teacher describes a lesson in which students are asked to *"Prepare a model of a sustainable city and justify your plan."* A math teacher offered this reply: "Design thinking is a process to solve real problems creatively. We follow design cycle to solve real life problems."

(6) the discipline specific nature of design.

As in our analysis of DP teachers' responses, we again found that some MYP teachers are eager to acknowledge design as a discipline quite distinct from their own. In some cases, this may have stemmed from a confusion between design and design thinking, where the former is a distinct discipline but the latter could be integrated within any discipline. Most teachers who included this idea in their replies seemed intent on recognizing the disciplinary distinction. One teacher of Individuals and Society made this clear by seeking to connect with a colleague who could bring this expertise: *"I could work closer with the Design teacher to find ways of incorporating design thinking to more topics of Individuals and Societies and doing more projects together."* Many teachers refer to the

"IB design cycle" as a programme level value, such as this science teacher who said, *"By using the MYP Design cycle approach to all project work, students are constantly referring to the cycle to make further progress."* Other teachers revealed that they recognize the value and importance of design and are familiar with the basic ideas of the design cycle. For example, a math teacher observed: *"By posing the scenario and students empathise and identify the problem, then analyse and develop prototype and test the solutions".*

How MYP teachers are integrating Computational Thinking

As in our analysis of the DP teacher responses, we again found that many MYP teachers consider open-ended problems as an important means of engaging CT. We will not duplicate that here in our list, but should stress that this approach of open-ended problem solving is again seen as a primary channel of addressing CT, likely occurring to teachers that both DT and CT are engaged in the same projects (i.e., quadrant one in the diagram provided in Section 1). Hence, while the use of open-ended problems is an important strategy or theme for inclusion of CT, this section will focus on themes that have not been reviewed above. The following six themes emerged from our reading of teacher responses: (1) Connections to design; (2) General inclusion of technology; (3) Integrating programmable hardware technologies; (4) Use of programming environments; (5) Focus on algorithms; (6) Working with data.

(1) Connections to design.

One idea that is common in MYP teachers' responses about how they include CT, is the connection of CT to design problems or processes. Indeed, many teachers seem to believe that CT typically happens in the context of open-ended projects where students are engaged in design. Of course, the design teachers were most likely to express this view. One design teacher said, *"Following with design cycle strands has helped me with computational thinking."* Another teacher said, *"Within the MYP design cycle there is a planning component that relies heavily on computational thinking. Specifically, it could be using algorithms, or Gantt charts to visualise practical processes."* One specific aspect of design that teachers cited was modeling, such as this reply from an MYP design teacher: *"Teaching digital design has enabled me to integrate computational thinking as a basic method. I introduce my students to software that enables them to model and create a product for their design project"*. Hence, just as in the PYP there is a recognition that by including modeling tasks in a design project, students will be engaged in computational thinking.

(2) General inclusion of technology

Similar to the patterns observed in DP teacher responses, we found that many MYP teachers feel that CT could be engaged by simply including technology generally, such as in the use of simulations or interactive Web sites. While this certainly may be true, it should be qualified that such technologies can only engage CT if they are used to help students formulate problems, think algorithmically, or any other dimensions of our definition. Simply including technology would not be sufficient in and of itself. Some examples of teachers' replies in this theme are the math teacher who said *"By integrating digital technology and simulations in investigation tasks"* be used in l is more prominent in the responses of design teachers. A design teacher replied, *"have tried to incorporate computers into design such as web sites, digital design and so forth as to have students use computational thinking."*

(3) Integrating programmable hardware technologies

This idea involves engaging students with programmable technologies like robots, 3D printers, or Internet of Things (i.e., Arduino and Raspberry Pi). Clearly, design teachers will have an advantage when it comes to integrating such technologically rich problem-solving tasks, and indeed this category of response was most common from MYP design teachers. One of them replied, *"We use mini games from "hour of code", or a robotics Unit, where students have to code a robot to navigate a maze or knock down objects in an order".* Another said, *"We attempted to reach programming skills at all MYP levels. Used robotics, Arduino and Raspberry Pi".* And still another: *"We do unit on Robotics using Lego EV3 that helps us to introduce computational thinking."* Hence, to the extent that they are available to teachers, adding such hardware elements to the curriculum can be a good strategy for invoking CT.

(4) Use of programming environments.

One form of computing that seems obvious to any teacher is that of actual computer programming. The advent of software environments like scratch and other "block-based" languages (i.e., where students actually manipulate the software visually in the form of blocks with different sizes and shapes) have allowed computer programming to become accessible in the middle years. Several MYP teachers made reference to specific forms of programming environments. For example, a design teacher said, *"Defining and developing units that encourage students to use SCRATCH to create their final digital design outcome."* Another design teacher described the use of *"CAD software for accurate 3d modeling*", where the acronym CAD refers to Computer Assisted Design (e.g., Google Sketch Up). Clearly, such activities would link well to the notion of 21st century competencies, as CAD is one form of work and a basic form of computer literacy that could serve students well in their working life.

MYP teachers of courses other than design often seem to place a higher level of responsibility for student learning on the software itself, such as this math teacher who observed, *"The best way to improve the use of computational thinking in my teaching would be to use better tools in the form of computational applications (e.g., Excel) and implement this thinking in each Unit"*.

(5) Focus on algorithms.

Finally, there was a recognition shared by some MYP teachers that algorithmic thinking is a form of CT, and that some curricular activities could benefit from this approach. One science teacher observed, *"We went on a field trip where the students had to find an algorithm to calculate the number of trees and plants present in that specific biome".* A math teacher added, *"Maths is about algorithms, we teach them steps to solve equations. You need to know the steps you do and follow them. We also have a specific section of the framework about algorithms."* An individuals and Society teacher suggested, "Actively expressing to students the need to break down issues into smaller steps and encouraging the use of reason more explicitly." This theme may be one of the most encouraging, as it directly taps into a dimension of CT and shows that some MYP teachers are able to see the value of engaging this form of thinking, in conjunction with their broader curricular goals.

The Primary Years Programme

How PYP teachers are integrating Design Thinking

With regard to the integration of Design Thinking, we examined PYP teachers along two age bands of students they teach: age 3-6 years, age 7-12 years. For those with younger students, we found the following main themes present: (1) play and creativity, (2) open ended problems, and (3) collaboration or group work. For those with older students, we found those same three strategies as well as the following: (4) integration of topics across disciplines, and (5) student-selected problems.

(1) Play and creativity.

Perhaps the most common reply from teachers of the younger students was, not surprisingly, that creativity and play would engage design thinking. This resonates with the dimension of creativity included in our working definition, and is seen in many responses, such as this teacher: *"I seek to develop activities that involve the development of the creativity of the students and that have the opportunity to build a personal result".* Another teacher cited the strategy of "*encouraging them to use creativity, analytical skills and team work to solve real world problems*". Teachers of older students also refer to creativity as an important strategy, such as through the inclusion of arts-based activities. One teacher said, simply: *"use of art and creativity".* Another expanded, *"Students should be engaged more with design thinking approach across the curriculum and the learning context, encouraging them to use creativity, analytical skills and team work to solve real world problems."*

(2) Open-ended problems.

There was widespread agreement amongst PYP teachers that the use of open-problems fosters design thinking, in all age levels. This reflects the thinking of MYP and DP teachers as well. Some teachers of very young students simply advocate for giving students play areas with blocks and art materials, which fosters creative thinking. Others were more specific such as this teacher of 3-6 year olds: *"During the unit of Animals, the learners were given a problem that an animal could face and they had to find ways to help this animal".* Or this teacher from the same age group who explained, *"During the Unit about Water the students need to come up with a solution on how to save water in our school and what people should start doing to keep our water sources clean... more open ended questions let students come up with different solutions to problems in our daily routine. Ex: we are out of paper/crayons, what should we do? How? Do you have a plan?"* In the upper years, teachers offered more sophisticated curricular connections, such as one teacher who said, "*planning, creating, testing and refining a design, e.g., a paper plane*". Several teachers describe the creation of theatre scenery and props as a design challenge, for example, *"My students made the scenery for the play. Made from scrap materials basis for theatrical performances".* One teacher of the upper grades summed up the following basic strategy: *"Give students an open-ended task with several possible outcomes. Students can choose how to approach the problem(s) and work on or offer potential solutions to the problem."*

(3) Collaboration.

As with the DP and MYP, many PYP teachers see collaboration as an important pathway or strategy to promote design thinking. In the younger years, collaboration also clearly has the benefits of promoting social skills and positive attitudes toward working with others. One PYP teacher of 3-6 year olds responded, *"working on group work, which helps students communicate ideas and design solutions*", or another who suggested: *"a pair or group working strategy … encouraging them to collaborate together throughout the subject".* In the higher age bracket (7-12 years) teachers became more explicit in how collaboration helps connect to design. One teacher offered, "*Students identified some environmental problems. In groups, they brainstormed solutions for these problems and presented their designs to their peers. Students received oral feedback from their peers."* Another described the following approach: *"During the unit STP titled "Save the Trees", after finding the causes of deforestation and their effect on the human and the environment, the students collaborated on finding solutions to preserve the forests."* Another specific example that was offered by a PYP teacher was the following: *"Students were well engaged in their fifth unit of inquiry, Cities. As they* *created their own design of cities, collaboratively. They had problems in the way of crafting the city, but they were able to solve the problem brilliantly."*

(4) Integration of topics across disciplines.

PYP teachers recognize that the connection of topics across disciplines offers a means of engaging students in design thinking. This strategy was suggested primary by teachers of the higher age groups. Several respondents cited the connection of mathematics one approach, such as the following example: *"We integrate the math when we can, but math is not integrated in every unit of inquiry".* Several others recognized the excellent connections offered by topics in health and social issues, as well as environmental science. The interdisciplinary constructs of STEM (Science, Technology, Engineering and Mathematics), and STEAM (where "Arts" are added to STEM) were often cited as a pathway to engage DT, such as the following: "*Introduction of creating Makerspace, STEAM activities and BP challenges around architecture, building and creating*", and also *"We do Stem Challenges in each unit, when they use design thinking in projects".* One teacher offered an idea for furthering this interdisciplinary approach by connecting across IB programs: *"Collaboration between Art and Design teachers from High school and Middle school"*

(5) Student-selected problems.

A final strategy suggested by PYP teachers in the upper age group was to actually engage students in defining the curricular problem, which recognizes the personal relevance of a meaningful problem. One teacher offered, "*Give the students the ability to decide the materials to create their own projects,*" or another who advocated the general strategy, "*By asking them to design questions on how to inquire their classmates*." Other teachers stayed within the bounds of a particular topic or assignment, but still advocated for students having voice in their assignments, such as *"With regards to taking action in every unit of inquiry, students are asked to identify a problem in their environment and then think about how we can go about solving that problem, keeping our audience in mind*". Another teacher offered this strategy, "students are asked to identify a problem in their environment and then think about how we can go about solving that problem, keeping our audience in mind." These responses demonstrate that PYP teachers are mindful of their students' engagement in design thinking, and exercising strategies to ensure this engagement. Open-ended problems that are informed by student voice remains a theme across the three IB programmes.

How PYP teachers are integrating Computational Thinking

As in the analyses of MYP and DP above, teachers from the PYP adopt strategies for engaging CT that are related to those for DT. And again, there is a general inclination to associate the use of technology, especially computer programming, with CT, which is not necessarily erroneous but would be a quite limited view on its own. That is, simply using computers would not be enough to guarantee CT, such as when students simply play a game or a math quiz on a Web site). Nor are computers necessary to engage CT, as reflected in our working definition above. Algorithms, problem decomposition, debugging and iteration are all forms of thinking and reasoning that could potentially be engaged without technology. PYP teachers do seem to be aware of this, and many of their replies involve activities that are not performed on computers, or that use technology in ways that invoke CT. The following themes were distinguished amongst PYP teachers' responses to these two items (about strategies for engaging CT): For the younger age levels, we found (1) finding patterns, (2) breaking problems into smaller parts, (3) the use of puzzles and problems, (4) math and number play, and (5) adding technology. Teachers of older age groups added many of those same strategies, as well as (6) computer games, (7) use of concept maps and flow charts, (8) robotics, and computer programming. As in the strategies for DT, there were also frequent references to the value of cross-disciplinary connections and open ended problems. Finally, it should be mentioned that many teachers reflected honestly that they really did not know how to integrate CT and needed more support.

(1) Finding patterns.

This is clearly a strategy that is commonly understood by teachers of young students. Several examples were offered, such as *"Give kids different shapes to find them in their lives"*, or *"Block play, Lego play, pattern play, are successful ways for integrating computational thinking".* These responses demonstrate a clear recognition that certain forms of play are an excellent source of formative thinking in the early years. Another teacher combined pattern recognition with the use of technology: *"We used the pc [computer] while learning what is pattern, where we can find it and how to create it and at last how to extend patterns".* Teachers of the older students also emphasized this strategy, such as this response: *'When they see a pattern in their environment, and then integrate it with subjects such as math where we have patterns too. They are curious about weather patterns".*

(2) Breaking problems into smaller parts.

This theme also was stated explicitly by several teachers, suggesting that it is a view held by many teachers, concerning how to establish early forms of computational thinking. One teacher of the younger age levels replied, "*decomposition - breaking down a complex problem or system into smaller, more manageable parts*", and another: *"Breaking bigger problems into smaller parts, easier for little children to follow and understand".* Thus, teachers are applying this strategy explicitly, and are aware of its connection to CT. It is noteworthy that decomposition is one of the dimensions of our working definition of CT. One teacher of older students did offer this strategy as well, suggesting that it is in use across the PYP: *"When we look at a unit problem (big idea), as a class we break it down into smaller part and then create a step by step plan on how to solve the problems. at the end of the year during the exhibition, they then get to do it by themselves."*

(3) Using puzzles and problems.

This was a common strategy, suggesting that PYP teachers understand how puzzle solving is connected to CT. One teacher of the younger students replied, "Other teachers recognized the "step-by step" nature of problem solving as being related to the algorithmic flow of computation. For example, one teacher offered, *"Planning a situation/problem that children can solve step by step".* Another provided a very similar reply, *"developing a step-by-step solution to the problem, or the rules to follow to solve the problem".* Teachers in the older years of PYP also refer to the value of problems for CT. One observed, *"students are given an open-ended problem-solving task approximately every two weeks. The students try to solve this and we discuss the methods for solving the problem. Computational thinking is also built into the trans-disciplinary inquiries."* They also suggested specific uses of problem-based learning that demonstrated their understanding of how it connects to CT. For instance, this teacher offered the following: *"Students were given to find a suitable classroom layout that would allow them to be in comfortable learning environment."* Another suggested a specific problem, *"Paleolithic people: creating maths problems about the expansion of agriculture regarding the fields they had available"*

(4) Number play, mathematics, and data.

PYP teachers realize the value of mathematics problems for engaging CT. Teachers of the early years typically referred to number sense, as well as the patterns mentioned above (e.g., "Teaching numbers and patterns by using colourful wooden blocks."). One teacher offered the following summary, *"Mathematics is the most difficult subject for the student, the role of the teachers on this area is giving opportunities with strategies in solving their problems (with tools or not)".* Another teacher suggested an approach to engage students in such mathematical reasoning: "*For example, to share their snacks with them by providing mathematical language, such as "you are taking quarter or half of the cake" or "could you please distribute the fruit to our class. we have 15 children today".* Teachers of the older students also invoked mathematics as a strategy, such as one who commented generally, "*Through maths, the children solve problems using systematic approaches*", and another who offered, "*Give then open-ended questions during mathematics, and used reasoning skill to find various solution of mathematics problem."* Finally, reflecting the emphasis placed on data and spreadsheets by teachers in the MYP and DP, some PYP teachers did observe the potential advantages of this approach, such as the following: *"Designing surveys and organizing information using Excel and PowerPoint".*

(5) Adding technology.

Many teachers simply understood computational thinking to demand the use of computers and technology. One replied "*integrate more technology in the classroom."* And another *"by using technology".* Others felt that simply adding the computers or technology would lead to productive applications (without necessarily specifying what those applications would be) – for example, "*Having more iPads in the class or having computers class more often.*" Some recognized the need to deeply integrate technology, without necessarily saying how this would be achieved (e.g., "*integrating digital resources in all subjects.").* Others offered some connection to specific topic areas, but still without explicating the role of technology: *"Our students have been able to use technology (iPads, Chromebooks) to learn, practice and assess their skills in Math, English, UOI, as well as in other areas (for example: SEL)".* In general, this strategy seems to be offered by teachers who are not considering the actual processes or dimensions of computational thinking, but rather just assuming that such processes would be engaged through any applications of technology.

(6) Computer games.

Many teachers recognized the potential value of computer games, as a means of developing computational thinking but also other topics. One observed, enthusiastically, "*Computer games are awesome for children to practice language, math, reading, science, social studies and -- everything. Group thinking challenges, fill in blanks, corresponding, etc.".* While no teachers from the younger age levels raised this strategy (despite some excellent available options for young learners that would likely engage CT), the teachers of older children did have both general beliefs as well as specific ideas about this strategy. One teacher suggested that it is, *"interesting and helpful to use computer games in order to teach them a broad spectrum of lessons, it would improve on multiple things and not just computational thinking."*. Another offered a specific approach of *"Using Minecraft to create a town"*.

(7) Use of concept maps and flow charts.

This idea appeared in several survey responses, suggesting that it is recognized by PYP teachers as being related to algorithms and relevant to students' development of CT. One teacher of older students said*, "We learned to do the work according to the algorithm, we used concept maps, we did the work ourselves and checked them according to the algorithm."* Another teacher (again, of older students) suggested the strategy of *"Using flow charts to show cause and effect in natural disasters… I often make a map of concepts through which students learn to see the problem and can then build an algorithm for research. Also, students learn to formulate questions for the expansion of knowledge in* *this area*". Hence, this approach of flow charts is seen as a means of directly engaging CT by allowing a more structured, algorithmic approach to ideas.

(8) Robotics and computer programming.

While robotics wasn't mentioned quite as often by PYP teachers as it was by those in the MYP, it was still recognized by several teachers as a strategy to engage CT. One teacher observed, *"students can think about how a robot can do what it does, while having fun trying to get it to move in certain ways.* Another replied that *"Children can be given opportunities to explore different technologies like robotics."* Thus, while robotics was not very common in PYP teacher replies, it did occur often enough to suggest that this approach is seen as a strategy for engaging CT. Similarly, while computer programming was not a common strategy, several PYP teachers did observe that some programming environments are accessible to students. For example, one teacher said, *"Using apps to do picture coding. I used Scratch when teaching cartesian coordinates. Students designed programs to slide, rotate and turn a shape across a cartesian plane."* As more and more devices (e.g., robots, or Arduino) become accessible to younger children, it seems likely that teachers in the PYP will find these tools and bring them into the curriculum as strategies to engage CT and DT alike.

Discussion

It is clear from the various strategies offered above, that teachers from across all three programmes are aware of DT/CT, and understand those competencies as being important to students' learning and overall development. There is a common recognition of the value of open-ended projects in which students must creatively apply the ideas and topics from the course. This strategy is prominent within PYP and MYP, but also appears frequently in comments from DP teachers. Second, many teachers see the opportunity to engage CT by using data, spreadsheets and quantitative modeling. In PYP, there was a clear consensus that engaging in number play and reasoning about shapes would s promote CT. Many teachers recognized the value of collaboration, for learning, as well as multi-disciplinary projects.

While the various priorities addressed above (collaboration, creativity, etc) are important dimensions of DT and CT, there are other dimensions, more specific to design and computing, that were less commonly addressed, such as algorithms and problem decomposition for CT, and iterative testing and revision for DT. These dimensions were occasionally mentioned and targeted by teachers but typically within the computer science or design courses. Teachers would apparently require further guidance in order to achieve a more comprehensive understanding and treatment of DT and CT.

Finally, there were many teachers who did not even choose to reply to these open-ended items. This may indicate a lack of time or interest in participating, but in many cases must be taken to indicate a lack of any substantive ideas to contribute. Moreover, there were many teachers – approximately 5-10% of all who replied to these items – who expressed limited understandings and lack of confidence in how to integrate DT and CT. Because the sections above were focused on capturing the strategies in place, these teacher responses were not given voice above. Here, we can summarize that many teachers expressed the need for more guidance, or simply said that they "didn't know how" to integrate DT or CT. Hence, there exists a spectrum of expertise with respect to this important challenge.

Next, we asked teachers to articulate the obstacles they perceive to integrating DT and CT. These are summarized in the next section, together with some considerations for the IB curriculum and professional development.

Section 4

What are the Key Challenges & Considerations for Integrating Computational and Design Thinking in IB Programmes?

Synthesis & Discussion

Section 4: What are the Key Challenges & Considerations for Integrating CT and DT?

In this section, we discuss some of the challenges confronting the three programmes, as gathered through further open-ended survey items. We then provide a set of considerations that might help respond to those challenges at the programme, course and school levels.

Challenges confronting IB teachers and programmes

Key take-aways (challenges)

- DP teachers feel there is too much required content and not enough curriculum time, for the introduction of project-based approaches, open ended problems.
- There is a need for clear assessments of DT and CT, in order to guide teachers' design of activities that incorporate or address those assessments.
- Teachers need more guidance in designing and enacting activities that use DT and CT.
- Some teachers, especially in the PYP, feel their students are not ready for such forms of curriculum.

Our survey included the following item (posed twice – once for DT and once for CT): *What are some obstacles that limit your ability to include design (computational) thinking in your teaching?* We again read all teacher responses and tried to synthesize common or recurring themes for each of the programmes. We present these below, with some discussion.

In the DP, teachers often cited issues with "*too much content*" to cover, and a corresponding matter of "*not enough curriculum time*". This suggests that they are aware of the value of open-ended problems and project-based learning, but do not feel that it is possible to employ such time intensive methods (i.e., the classic tension of "depth vs. breadth"). Competency-centred views of curriculum hold a strong value for deep, project-based learning, which will come at a cost of curriculum time. The DP is challenged to allow for this, despite the evidence from research suggesting that students learn more deeply and gain critical competencies. This challenge would confront the strong emphasis placed by the DP on content-heavy assessment, and support the introduction of explicit assessments for competencies (e.g., within the IA), as well as structures for multidisciplinary design projects. Another challenge emphasized by many DP teachers was the lack of strong examples of "*how to do this*". Some asked how DT and CT should be assessed, and asked for TSM that illustrated such curriculum and assessment. Another teacher mentioned that "*If I'm not required to assess these, and students don't feel that pressure, it will be difficult to prioritize*". Other teachers cited a lack of resources such as worksheets, guides and starter activities, as well as a lack of knowledge and need for professional development.

MYP teachers resembled their DP counterparts in some ways, although fewer cited the heavy content requirements. Still, there were some who argued they needed more time for projects (e.g., in Math and Science). Given the emphasis placed within the MYP on design and project-based learning, this would suggest the need for some strategy of infusing all MYP courses with a greater emphasis on problem solving, creativity, and data-driven reasoning. Some teachers described a need for more clarity in the TSM about how to address these constructs - especially CT. There was a general appeal for more resources. Apparently, three is awareness of the need for project-based learning and open-ended problems, but a lack of clear guidance about what those look like for specific MYP courses. Similar to their DP peers, teachers from the MYP described a lack of knowledge and need for professional development. Finally, some teachers seemed to feel that their students were "*not ready*" for such curriculum. These teachers suggested that MYP needed to do a better job of preparing the students for such learning, and they did not know how to help orient students and get them started along this progression.

In the PYP, some teachers surprisingly maintained that they need more curricular time devoted to integration of DT and CT, which is interesting given the level of local control PYP schools have, in managing their programmes of inquiry. This suggests that some teachers may feel a sense of constraint or limitation imposed by their school's inquiry plans, and could use more support in adapting those plans to support DT and CT integration. Many teachers described a lack of confidence in themselves for undertaking anything to do with technology, and a lack of resources for computation and design. Others describe a general lack of knowledge about integrating DT and CT, and a need for professional development. Many felt that their school does not prioritize such learning, and provides insufficient budget for resources. Finally, there were a number of teachers who felt that their students were "not yet ready" for engagement in DT and CT, either because of perceived behavioural issues, or because they believed these forms of learning are developmentally inappropriate.

Considerations

Key take-aways (considerations)

- Improve the guides, making explicit reference to DT and CT as a basis for powerful teaching and learning, and as important 21st century competencies.
- Assess DT and CT explicitly, so that teachers and students take them seriously
- Emphasize programme-wide focus on project-based curriculum, and revisit breadth of required content.
- Create TSM with explicit guidance and rich examples for teachers and make DT and CT explicit within those examples.
- Foster Interdisciplinary collaborations amongst teachers to allow application of ideas from one course within designs or projects from another.
- Find topics that engage DT and CT jointly
- Support the exchange of programs of inquiry and lesson designs amongst IB teachers.
- Create programme-level plans for teacher professional development that can support schools in helping teachers become more knowledgeable and reflective in their practice.

Within-programme considerations

For the DP, a specific consideration would be to first engage in some re-design of curriculum expectations, reducing the amount of core content, to add multidisciplinary projects. Strengthening interdisciplinary connections between computer science, mathematics, and sciences could be one strategy (e.g., creating a multidisciplinary project requirement). For this age group, career identity development is vital. Perhaps DP could examine the Career programme (CP) borrowing ideas and approaches like (1) reflective projects with a career focus, (2) personal and professional skills groups, (3) focus on specific skills learning. By adding some of these elements, DP could support students' sense of meaning and purpose in learning, help them think about their broader education and career plans, and prepare them for the broad spectrum of tasks that will be coming their way in university and beyond.

For the MYP, one specific consideration would be the explicit integration of DT/CT into the programs of inquiry, referring to the dimensions of our working definitions. This could entail the production of some clear examples and resources. It will be important to consider the learning progressions from PY throughout the MYP: where will students be starting out, and what are the specific goals, with regard to DT and CT? Most important would be to add a clear emphasis on DT and CT at the programme level (i.e., not just in the Design course), and include dedicated TSMs. While the design course is an excellent opportunity to equip students with solid foundations for design thinking, it would only be through their meaningful application of DT and CT within their other courses during the MYP that these competencies could be solidified. Supporting the exchange of lesson and assessment designs amongst MYP teachers across the programme could also provide a powerful source of content and help to disseminate effective designs.

For the PYP, which already has a clear commitment to competency-centred learning, greater emphasis could be placed on students' learning progressions, and how these can be supported in the programmes of inquiry: Where do students start, in relation to problem-centred, creative and collaborative approaches, and how can we support their development? IB can provide more structured help to teachers design developmentally appropriate activities. Specific guidance could be offered, around DT and CT, to help teachers understand how these competencies will be impacted by a variety of approaches. More effort could also address the inclusion of DT and CT throughout the programme, including a clear narrative about how design and computation are things that PYP students learn about, and how these will be critical for success in the MYP and beyond. One way to enable the growth of knowledge within the PYP community around these competencies is to foster an exchange of inquiry designs across the programme. Teachers can be supported to document and then share their designs in an online space, including any important pedagogical notes (i.e., about how to ensure the design succeeds, or what kinds of issues students encounter).

Cross-programme recommendations

To begin, the IB should undertake to establish clear positions about 21st century competencies and their role within the various programmes. Some official position should be articulated, perhaps informed by this report, to inform some clear recommendations that would in turn help to guide programme curriculum managers in developing the next generation of guides and TSM. Emphasis should be placed on TSM development that captures a competency-centred approach, illustrating what forms of activity are entailed within a curriculum unit, and how such activities engage the targeted competencies (e.g., DT and CT). These new TSM should emphasize the critical teaching practices associated with successful implementation of such curriculum, including discourse patterns, and other practices (e.g., for monitoring of student progress).

New versions of the Guides and TSM can help make explicit connections to DT and CT, offering teachers clear direction and insight about the learning progressions that would engage DT and CT as instructional priorities. The guides could also describe the relevance of DT and CT to the instructional domain. There are also some clear overlaps or connections between DT and CT that make the two forms of thinking well suited for the same curricular tasks. Collaboration and creativity are not explicitly named within the CT dimensions but could certainly promote the forms of problem formulation, decomposition and representation that are central to CT. Hence, there are alignments between these two forms of thinking. By using open ended problems, and engaging peers in collaborative design, it should be possible to engage both DT and CT, to the extent that students are able to produce some problem formulations and representations, and even progress toward more formal algorithms and debugging.

CT in particular could be connected with the wider goal of technology integration – i.e., by helping DP teachers integrate technology learning environments such as Nearpod or Padlet or Google Drive, in which they will need to think more actively with technology, collaborate with peers, and struggle with the usual issues of user interfaces, files and versions, editing permissions, etc. While these elements may not be explicitly engaging computation, they will add some element of problematizing and encourage technical literacies for all students. In addition, many technology environments do require algorithmic approaches, pattern recognition and problem-based thinking.

In social studies courses, an opportunity for linking to DT and CT could be found in linking to digital and social media within society, as vital social movements and dynamics of change (e.g., the rise of the Internet, the dot com era, design and maker culture). Students could consider parallels between the industrial revolution and the information age, where the power of computation has dramatically boosted the economy and changed lifestyles and the nature of work. They could also try to understand the rise of automation and machine learning as new movements, as well as the role of social media and advertising on the internet. "Fake news" and the need for critical thinking could further engage such discussions, as simply understanding some of these ideas could be critical to students' own identity formation, schooling decisions, and engagement in competencies like DT and CT.

Another strategy, for any given course, could be to consider design and computation within the landscape of professional practice within the relevant disciplines (e.g., mathematics, chemistry, engineering). Course designers could identify where design is happening and how computation, technology and media are playing a role within the field, which could add a level of personal and social relevancy of the course, as well as vital context, meaning and purpose for students. Future versions of the course guide could help provide such a context for the topic of study, which could promote interdisciplinarity and give a sense of direction to instructors and programme coordinators. The Teacher Support Materials can then provide some guidance about how to build in such career connections, foster interdisciplinarity, and support a competency-centred approach. This can help respond to the growing calls from tertiary education to foster 21st century competencies including design and problem solving, as well as a focus on socioemotional factors like resiliency, self-efficacy and productive collaboration.

We must acknowledge that no learning goals will be taken seriously (by students or teachers) if they are not assessed – an observation that seems particularly true within the IB. Throughout education, assessments are the coin of the realm. But this provides a real opportunity for the various IB programmes and courses to assert the priorities of DT and CT, as well as other core competencies such as critical thinking, creativity, communication and collaboration. Of course, any assessment comes at a cost of instructional time that would be given over to ensuring student success, and this may implicate some revision of content and process learning goals.

Moreover, teachers are not usually prepared to shift their modes of instruction into more active forms of learning that foster student competencies. The IB shows great strength in its aims towards increasing the development of comprehensive teacher support materials, but these will not be sufficient in themselves to support dramatic shifts in practice. There will need to be further professional development around new approaches to competency-centred curriculum and assessments. Possible approaches could include the creation of online micro-credentials for IB teachers, leveraging existing MOOCS that address teachers' integration of inquiry and technology, or active learning design, as well as the creation of new professional development courses. Programmes could offer supports and guidance for teacher professional development workshops, which schools could customize and implement (with some form of accountability).

Across the programmes, teachers should be supported in professional development around issues of competency-centred instruction. Some teachers have reservations about such methods, believing, for example, that computational thinking can only be engaged in computer science or computer programming activities. Others believe that inquiry and project-based learning are less valuable uses of curriculum time than lecture and recitations. Teachers should be engaged in professional discussions regarding these core debates, as well as their own specific courses and disciplines. It is important that the IB support a normed understanding of these challenging ideas, within its teacher community.

Finally, it must be recognized that the core purpose of education is shifting. Debates concerning competency-centred instruction are about more than just adding some new topics to the course guides and TSM. Rather, these debates amount to a challenge – for IB leaders, teachers' and students – to re-frame their understandings about the general nature and purpose of learning. Rome wasn't built in a day, and schools around the world are engaged in these important conversations. There is a form of climate of change occurring in education now, with many countries adopting new learning standards (the NGSS in the US, and the inclusion of 21st century competencies in Canada). Allan Collins' 2017 book, *What's Worth Teaching* provides an excellent point of reference for this ongoing discussion.

Future research

There are several topics that could warrant further research, by the IB or scholars more widely. The first is concerned with school and programme change, and how school leaders and curriculum coordinators can come to support the implementation of CT and DT. This will entail some analysis of institutional norms and policies, how values come to be adopted across the institution, and how change can be distributed throughout the IB community. Another interesting project could be to capture some case studies where DT and CT were implemented successfully and with positive outcomes, carefully documenting how the various dimensions are present, and how the activities supported student learning. Another possible project could be the formulation of pragmatic design principles that could guide the design of DT and CT-infused curriculum and assessments. These would likely be cast at the programme level and possible target specific courses (e.g., principles for DP physics). Some of these could be discerned from the educational research literature, and some could be captured through pragmatic research (e.g., soliciting effective designs from IB teachers). Finally, this research could not examine fully how the IB Career Programme is implementing and integrating DT or CT. It would be worthwhile given the strong connections to career skills these competencies hold for the IB to conduct research with the Career programme.

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Appendix A

Annotated Bibliography

Appendix A. Annotated Bibliography

The following short summaries are provided for papers that we felt were central to our discussion of the themes above. For each theme, we have identified 2 or 3 "key papers," for which we provide short summaries, and "highlights". These are papers we feel would be of value for further reading.

Key reviews. These are existing review papers that discuss CT and DT across a range of research literature. They are reviews that we feel are accessible and relevant to the practitioner community.

1. Grover, S., & Pea, R. (2013). Computational thinking in K-12: A review of the state of the field. Educational Researcher, 42(1), 38-43.
   - Described how scholars conceptualized and operationalized CT;
   - Summarized research efforts on environments and tools that foster CT and approaches to assess CT;
   - Pointed out the lack of empirical inquiries, suggested earlier bodies of literature from which CT research should draw lessons from.

2. Lye, S. Y., & Koh, J. H. L. (2014). Review on teaching and learning of computational thinking through programming: What is next for K-12? Computers in Human Behavior, 41,51-61.
   - Reviewed 27 intervention studies on developing CT through programming;
   - Pointed out the gap in research on computational practices and perspectives;
   - Instructional strategies reviewed include constructionism-based problem-solving, scaffolding, and reflection activities.

3. Sullivan, F. R., & Heffernan, J. (2016). Robotic construction kits as computational manipulatives for learning in the STEM disciplines. Journal of Research on Technology in Education, 48(2), 105-128.
   - Reviewed the use of robotics construction kits (RCKs) in K-12 STEM learning;
   - RCKs are conceptualized as computational manipulatives;
   - RCKs can support direct instruction in robotics, serve as tools to learn other content, provide immediate feedback, support CT development beginning with a lower anchor of sequencing and finishing with a high anchor of systems thinking.

4. Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017). Demystifying computational thinking. Educational Research Review, 22(November), 142–158.
   - Provided a working definition of CT focused on the conceptual foundation required to solve problems effectively and efficiently with solutions that are reusable in different contexts;
   - Categorized CT into six main facets: decomposition, abstraction, algorithm design, debugging, iteration, and generalization.

Theme 1. Curriculum and learning progressions

CT:

1. Sneider, C., Stephenson, C., Schafer, B., & Flick, L. (2014). Exploring the science framework and NGSS: Computational thinking in high school classrooms. *The Science Teacher*, *81*(5), 53–59.
   - Present a Venn diagram that shows how they see the relationship between mathematical and computational thinking;
   - The diagram illustrates that analyzing and interpreting data is common to both mathematical and computational thinking, as are problem solving, mathematical modeling, and statistics and probability.

2. Weintrop, D., Beheshti, E., Horn, M. S., Orton, K., Trouille, L., Jona, K., & Wilensky, U. (2014). Interactive Assessment Tools for Computational Thinking in High School STEM Classrooms. In D. Reidsma, I. Choi, & R. Bargar (Eds.), *Proceedings of Intelligent Technologies for Interactive Entertainment* (pp. 22–25). Chicago, IL, USA.
   - Presents a pair of online, interactive assessments designed to measures students' computational thinking skills;
   - The computational tools used in the assessments enabled students to analyze data with dynamic visualizations and explore concepts with computational models.

3. Sengupta, P., Kinnebrew, J. S., Basu, S., Biswas, G., & Clark, D. B. (2013). Integrating computational thinking with K-12 science education using agent-based computation: A theoretical framework. *Education and Information Technologies*, *18*(2), 351–380.
   - Identified the synergies between CT and scientific expertise using a particular genre of computation: agent-based computation;
   - Proposed a set of guidelines for designing learning environments on science topics that can jointly foster the development of computational thinking with scientific expertise;
   - Described a learning environment that supports CT through modeling and simulation to help middle school students learn physics and biology.

DT:

1. Crismond, D. P., & Adams, R. S. (2012). A detailed discussion on what teachers need to understand and do to help K-16 students improve their design capability and learn through design activities. Details 9 design strategies and associated patterns and how to recognize and assess student progress from novices to experts.
   - Describes key performance dimensions for doing informed design
     - Learning while designing
     - Making and explaining knowledge-driven decisions
     - Working creatively to generate design insights and solutions
     - Perceiving and taking perspectives intelligently
     - Conducting sustained technological investigations
     - Using design strategies effectively
     - Integrating and reflecting on knowledge and skills

2. Ho, C. H. (2001). Breaks down how novices and experts decompose design problems in order to come up with solutions. Expert design thinkers break problems down into several well-structured subproblems, whereas novices quickly narrow down to a single problem/solution.
   - Goes into depth on all the different problem-solving strategies of a single novice and expert designer;
   - Contrasts expert and novice designers' approaches to thinking about and solving the problem;
   - Highlights the need to support students in developing decomposition strategies.

3. Wrigley, C., & Straker, K. (2017). This paper analyzes 51 post-secondary courses that teach Design Thinking across 28 countries to understand *what* (e.g., content) is being taught and *how* (assessment and learning models) it is being taught. From this analysis, the authors introduce the Educational Design Ladder - a means for staging the delivery of DT content, and progressively guiding students through their DT development.
   - Highlights five key themes from the analysis of what (content) Design Thinking was taught, and of how (assessment and learning modes) it was taught
     - Theories, methods and philosophies
     - Product focus
     - Design management
     - Business management
     - Professional development.
   - The first 2 are likely to be most relevant to the IB program.

4. Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important?. *Review of Educational Research*, 82(3), 330-348.
   - Though a literature review of design papers, this article outlines the characteristics of DT (Table 2 in this paper is very useful in understanding these characteristics);
   - Discusses what separates a novice and expert designer (novices tend to go for a depth-first approach, where experts go for a breadth-first approach to design);
   - Argues for what makes DT important (helps people tackle complex problems).

Theme 2. Assessment

<u>CT:</u>

1. Basawapatna, A., Koh, K. H., Repenning, A., Webb, D. C., & Marshall, K. S. (2011). Recognizing Computational Thinking Patterns. *Proceedings of the 42nd ACM Technical Symposium on Computer Science Education - SIGCSE '11*, 245.
   - Computational Thinking Patterns are abstract programming patterns that enable agent interactions not only in games but also in science simulations;
   - a Computational Thinking Pattern Quiz tested the participants' ability to recognize and understand patterns in a context removed from game programming;
   - participants, for the most part, were able to understand and recognize the patterns in a variety of contexts.

2. Dagiene, V., & Stupuriene, G. (2016). Bebras - A sustainable community building model for the concept based learning of informatics and computational thinking. *Informatics in Education*, *15*(3), 25–44.
   - Introduced the Bebras model using ten years of observations in implementing the contest in different countries;
   - The model is essentially based on democratic and inclusive education values;
   - Discussed reasoning on innovated learning informatics and strengthening computational thinking by utilising carefully selected informatics concepts.

3. Werner, L., Denner, J., & Campe, S. (2012). The Fairy Performance Assessment : Measuring Computational Thinking in Middle School. *Proceedings of the 43rd ACM Technical Symposium on Computer Science Education - SIGCSE '12*, 215–220.
   - A performance assessment tool for measuring CT in middle school;
   - Contextualized in game-programming courses and a block-based programming environment;
   - Assessment tasks are scenario-based.

DT:

1. Gijbels, D., Dochy, F., Van den Bossche, P., & Segers, M. (2005). Excellent review of the literature and history of Problem-Based Learning (PBL), the role of the teacher, and how it has been assessed over the years. Provides a rich list of different assessment approaches for PBL & DT drawn from existing research in the field.
   - Provides a 5-point scale that clearly outlines the kinds of problems that should be used to assess DT & PBL learning;
   - Argues that DT & Problem-based learning (PBL) assessment requires students to analyze and solve problems relevant to their domain.

2. Barron, Schwartz, Vye, Moore, Petrosino, Zech, and Bransford (1998). Outlines an approach to designing, implementing, and evaluating problem- and project-based learning, with a particular focus on design-focused assessments. Provides evidence of problem-based learning and assessments to support students' domain learning.
   - An excellent example of DT style cross-domain assessments where students need to "design a chair" and a "playhouse" to assess their geometry knowledge.

3. Adams, R. S., Turns, J., & Atman, C. J. (2003, November). What could design learning look like. In *Expertise in Design: Design Thinking Research Symposium* (Vol. 6).
   - Examines the difference between how expert and novice designers completed a similar design task;
   - Created a continuum of design expertise across several dimensions (e.g., cognitive, process, affective);
   - This design expertise is understood through 4 "windows"
     1) Design Process Window;
     2) An Adaptive Expertise Window;

3) A Systems Window;
4) Writing as Design Window.

Theme 3. Learning contexts and environments

CT:

1. Brennan, K., & Resnick, M. (2012). New frameworks for studying and assessing the development of computational thinking. *Annual American Educational Research Association Meeting, Vancouver, BC, Canada*, 1–25.
   - One of the seminal papers in CT and the Scratch program.
   - Attempted to assess how design-based learning activities – in particular, programming interactive media – support the development of computational thinking in young people.
   - Presented a computational thinking framework that included three dimensions: computational concepts, computational practices, and computational perspectives
   - Described approaches to assessing these dimensions, including project portfolio analysis, artifact-based interviews, and design scenarios.

2. Resnick, M., & Rosenbaum, E. (2013). Designing for Tinkerability. In Honey, M., & Kanter, D. (eds.), *Design, Make, Play: Growing the Next Generation of STEM Innovators*, pp. 163-181. Routledge.
   - Combines DT and CT together through the act of tinkering;
   - For the authors, tinkering is characterized by playful, experimental, iterative style of engagement, in which makers are continually reassessing their goals, exploring new paths, and imagining new possibilities;
   - Authors argue that digital environments can support tinkering by allowing for immediate and inspectable feedback;
   - The authors also state the need to emphasize the process over the product; setting themes, not challenges; combining "diving in" with "stepping back"; and engagement with people, not just materials.

DT:

1. Carroll, M., Goldman, S., Britos, L., Koh, J., Royalty, A., & Hornstein, M. (2010). Destination, imagination and the fires within: Design thinking in a middle school classroom. *International Journal of Art & Design Education*, 29(1), 37-53.
   - Looks at how a Design Thinking curriculum was integrated into a grade 7-8 Geography class;
   - Has a slightly modified version of the traditional DT model that may be of interest to readers (the breakdown is quite informative);
   - Explicated 3 key design themes for integrated DT:
     - Design as Exploring;
     - Design as Connecting;
     - Design as Intersecting.

2. Jona, K., Penney, L., & Stevens, R. (2015). 'Re-mediating' Learning. *International Society of the Learning Sciences*, Inc.[ISLS]
    - Introduces a learning platform called FUSE.
    - FUSE allows students to chart their own learning path through a focus on them designing solutions to challenges.
    - The FUSE website provides scaffolds to help students in their DT, and are faded as students' progress.

3. Kangas, K., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2013). Design thinking in elementary students' collaborative lamp designing process. *Design and Technology Education: An International Journal*, 18(1).
    - Discusses elementary design students collaborative design of a table lamp;
    - Intentionally fostered professional designing, multimodality, and critical understanding of the design practice among students;
    - Discusses the different ways the students engaged in DT discourse and their use of DT tools;
    - A nice example of how design can play out in elementary schools.

Theme 4. Teacher practice and professional development

<u>CT:</u>

1. Angeli, C., Voogt, J., Fluck, A., Webb, M., Cox, M., Zagami, J., … Zagami, J. (2016). A K-6 computational thinking curriculum framework: Implications for teacher knowledge. *Educational Technology & Society*, *19*(3), 47–57.
    - Discussed the design of the curriculum based on a generic computational thinking framework with a focus on real-world problems;
    - Discussed the knowledge teachers need to teach the curriculum within the framework of technological pedagogical content knowledge.

2. Yadav, A., Mayfield, C., Zhou, N., Hambrusch, S., & Korb, J. T. (2014). Computational thinking in elementary and secondary teacher education. *ACM Transactions on Computing Education*, *14*(1), 1–16. https://doi.org/10.1145/2576872
    - Reported a study on designing and introducing computational thinking modules and assessing their impact on preservice teachers' understanding of CT concepts, as well as their attitude towards computing;
    - Results demonstrate that introducing computational thinking into education courses can effectively influence preservice teachers' understanding of CT concepts.

<u>DT:</u>

1. Noweski, C., Scheer, A., Büttner, N., von Thienen, J., Erdmann, J., & Meinel, C. (2012). Towards a paradigm shift in education practice: Developing twenty-first century skills with design thinking. In *Design thinking research* (pp. 71-94). Springer, Berlin, Heidelberg.
    - Looks at the connections between 21st Century Skills and DT;

- Talks about the challenges teachers face when learning how these skills apply to their classrooms;
- Compares teachers trained with DT coaches compared to teachers trained in Dewey's constructivist approaches;
- Post assessments indicated the design-focused approach was more effective across several affective metrics.

2. Mentzer, N., Farrington, S., & Tennenhouse, J. (2015). Strategies for teaching brainstorming in design education. *Technology and Engineering Teacher*, *74*(8), 8.
   - Outlines techniques to support brainstorming during design tasks through the lens of a grade 12 engineering curriculum,
   - The 6 main techniques are:
     - The diverge/converge technique;
     - Decomposition activity;
     - The Inputs technique;
     - Using props;
     - Deck of cards technique;
     - Relaxation technique.

3. Bowler, L. (2014). Creativity through "maker" experiences and design thinking in the education of librarians. *Knowledge Quest*, *42*(5), 58.
   - Discusses how the design of a maker and design thinking experience for library and information sciences students to help them understand the importance and value of these experiences for their visitors.
   - By doing these activities it demystified the design process for the students and made them more receptive to using them in their future work.

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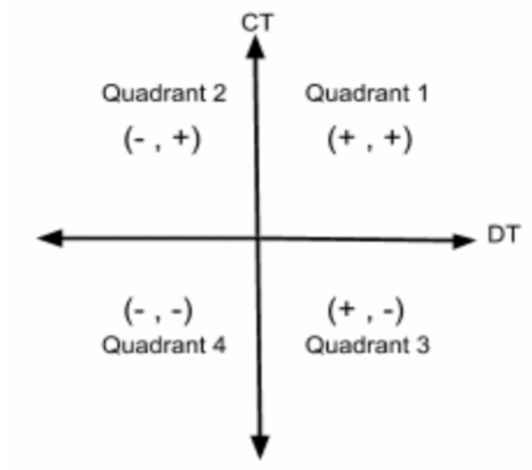
Appendix B

Annotated List of Resources

Appendix B. Annotated List of Resources

In the literature review, we recognized that curriculum activities and resources which engage CT or DT often engage both of those competencies, to some extent. We presented a grid with four quadrants, where the top right corner represents activities or resources that are strong in both DT and CT, and the bottom left being weak in both. Below, we provide a table of resources that are strong in at least one of the two forms of thinking, and typically connect with the other to some extent. These can be considered as falling within quadrants 1, 2 and 3 of the diagram. For each resource, we offer a link, an appropriate grade level or range, courses or topic areas where it might be relevant a description of what kind of resource, and some notes.



#	Title & Links	CT/DT	Grade Level	Courses	Resource Types*	Notes
1	CS Unplugged (https://classic.csunplugged.org/)	CT+ DT-	All ages	CS and non-CS	Learning activities	A collection of free learning activities that teach Computer Science through engaging games and puzzles that use cards, string, crayons and lots of running around.
2	Google for Education: Exploring Computational Thinking (https://edu.google.com/resources/programs/exploring-computational-thinking/)	CT+ DT-	Teachers		Professional development	The resources, including the curated collection of lesson plans, videos, and other resources were created to provide a better understanding of CT for educators and administrators, and to support those who want to integrate CT into their own classroom content, teaching practice, and learning
3	International Challenge on Informatics and Computational Thinking (https://www.bebras.org/)	CT+ DT-	Age 5 - 18	CS and non-CS	Computational thinking tasks	The Bebras challenges are made of a set of short problems called Bebras tasks and are delivered online. The tasks are fun, engaging and based on problems that computer

						scientists often meet and enjoy solving. The tasks can be solved without prior knowledge but instead require logical thinking.
4	Projects GUTS (https://teacherswithguts.org/resources)	CT+ DT+	K-12	CS, Science, Math	Lessons	Project GUTS — Growing Up Thinking Scientifically — is an integrated science and computer science programme for middle school students serving schools and districts internationally. Teacher resources include a variety of classroom-ready lessons.
5	ScratchEd (https://scratched.gse.harvard.edu/)	CT+ DT+	K-12	CS	Activities, assessments, lessons	An archive of discussions, resources, and stories around the use of Scratch block-based programming language in education.
6	Math Modeling with R (https://learn.concord.org/rmath)	CT+ DT+	High School	Mathematics	Activities, assessments, built-in R programming environment	Math Modeling with R (RMath) engages students in solving real-world problems with mathematical modeling and computational thinking practices. RMath provides classroom-ready modeling activities and web-based R for computing, data analysis, graphing, and programming.
7	Common Online Data Analysis Platform (CODAP) https://codap.concord.org/	CT+ DT-	Grades 6-14	STEM	Online data analysis platform and classroom-ready data science activities	CODAP is free educational software for data analysis. This web-based data science tool is designed as a platform for developers and as an application for students in grades 6-14.
8	SageModeler (https://sagemodeler.concord.org/)	CT+ DT+	Grades 6-12	STEM	Computational modeling	Free, web-based, and open-source software to engage students in systems thinking through

					environment and activities	designing, building, and revising models. Classroom-ready lessons and activities.
9	MIT App Inventor (https://appinventor.mit.edu/)	CT+ DT+	Grades 6-14	CS, STEM	Visual programming environment and activities	MIT App Inventor is an intuitive, visual programming environment that allows everyone – even children – to build fully functional apps for smartphones and tablets.
10	FUSE Studio (https://www.fusestudio.net/)	CT- DT+	Grades K-12	STEAM	Pre-designed challenges	FUSE Studio is a studio-approach to STEAM learning that allows students to choose their own interest/learning paths through facilitated design.
11	MIT Lemelson JV Inventeams (https://lemelson.mit.edu/inventeams)	CT- DT+	Grades 6-12	STEM	Designed Invention-based activities, activity guides, "inventor handbook"	MIT Lemelson Inventeams is a grant awarding programme that supports grade 6-12 students to advance their design projects and learn effective design practices.
12	WISE (http://wise.berkeley.edu)	CT- DT+	Grades 4-12	STEM	Pre-set and authorable activities and assessments	For 20 years, the Web-based Inquiry Science Environment (WISE) has offered a range of creative projects for middle and high school science. For example, designing and building a solar oven.
13	Loft (https://loft.io/)	CT- DT+	Any	Any design work	Peer feedback tools, design process guides, badges and other	Loft is an online platform for growing and supporting DT processes. Teachers and coaches can use Loft to teach design processes and monitor how teams are doing.

					recognition systems	
14	Stanford d.school (https://dschool.stanford.edu/)	CT-DT+	Any	Any	Resources for supporting the DT process, activities to support DT mindset. Also has a virtual crash course on DT (for teachers and students)	d.school is the information and training hub for DT at Stanford (one of the pioneers of modern DT approaches). It is mostly a resource space for all the different tools and approaches used by the d.school. There are no specific activities, but the overall resources can be quite useful.
15	Shape by Ideo (https://www.shape.space/)	CT-DT+	Any	Any	A tool to support creativity, idea refinement, and collaboration in the DT process. Includes IDEO best-practices templates	**$5/month subscription.** Could be a useful tool for a class or group of students who want a well-designed platform designed by one of the leaders in DT. They might do a deal for education purposes, but it is not started explicitly on the website. Still a good site for understanding DT processes and tools.
16	Design Thinking for Educators by IDEO (https://designthinkingforeducators.com/)	CT-DT+	Grades K-12	Any	Outlines the process and methods of design, the Designer's	Can be used in classrooms to both support DT in the class and for educators who want to use DT to address issues or opportunities in their schools.

					Workbook (adapted specifically K-12 education).	
17	IDEO's DT resources (https://designthinking.ideo.com/)	CT-DT+	Any (not specifically education focused	Any	Resources for brainstorming, creative confidence, and DT broadly	The resource section on this page could be very useful for getting ideas/approaches for how to think about and enact DT. It isn't organized in any way, but it is curated and vetted by IDEO.
18	Design Thinking Method Cards	CT-DT+	Any	Any	Cards for thinking about the DT process and help focus ideas and discussion	There are many of these, but here are a few good ones. They can be helpful and highly visual and tangible thinking tools (Note they are not specifically K-12 and some can be expensive): https://www.ideo.com/post/method-cards https://www.trytriggers.com/ https://methodkit.com/research-method-cards/ https://www.boardofinnovation.com/tools/brainstorm-cards/ https://designyoursprint.com/designthinking-en/

Fostering Computational Thinking and Design Thinking in the IB PYP, MYP and DP

Appendix C

Course Summaries from Curriculum Audit

Appendix C. Course Summaries (Audit Coding)

This appendix provides the detailed coding summaries of the courses in our curriculum audit. There are 6 courses for the DP (Physics, Geography, Computer Science, Design Technology, Mathematics and Chemistry), 4 courses for the MYP (Mathematics, Science, Design, and individuals and Society), and PYP Scope and Sequences documents for Math, Learning & Teaching, Science, Social Studies, and Technology Integration.

The Diploma Programme

1. DP Physics

One distinguishing feature of the DP Physics course is its depth of treatment of the physics concepts. We were very impressed by the high level of conceptual coverage, in both the Standard and High Level versions. The assessments were clearly on par with, if not more advanced than those of an AP physics course. One consequence of this high level of content is that there is not as much time or space in the curriculum for open ended design, iterative refinement, creativity. There were some connections to DT and CT - particularly in the Engineering Physics area, although we recognized that this is not a central topic. Overall, we recognized the opportunity to connect physics with design -- such as in the group 4 project, and some of the labs as well (ie, iterating, to get progressively better results). The HL topics are not easy targets for adding design (maybe electromagnetic induction?). Overall, the best aspects of DT to consider, in regard to physics, are the connection to real world problems, creative thinking, and collaboration. These elements are at the heart of science, are well represented in the Nature of Science section, and are also common to most inquiry and active learning designs.

We saw clear opportunities in the guide to add DT to the introductory matter, where much effort is given to express the nature of science, including its social and international aspects. If there were to be any new DT dimensions added to the formal assessment expectations, this would be treated in the assessment objectives as well as in the internal and external assessment areas. In this physics guide, the front matter had plenty of opportunity to draw explicit connections to CT - in Aims, Objectives, Links to Middle Years, mathematical requirements and experimental skills. Much of those would also be places where DT could be connected as well.

With regard to computational thinking, it was much harder to see any strong connections, nor any clear opportunities to make improvements that did not require substantive investments in curricular time and direction. In the syllabus topics, the Measurement and Evaluation unit was one place where there could be promising connections. In other unit topics, including labs, there could be a project assignment where dimensions of computation such as *decomposition, pattern recognition, iteration* were made more salient. The front matter of the Guide and Teacher Support Materials contains ample opportunity to draw explicit connections to CT - in Aims, Objectives, Links to Middle Years, mathematical requirements and experimental skills. Much of those would also be places where DT could be brought in as well. In the syllabus topics, the Measurement and Evaluation unit was one place where there should be promising connections, but in any of the other unit topics, including labs, there could be a project assignment where computation, decomposition, pattern recognition, iteration were more explicitly connected to the notion of CT.

Opportunities and Considerations

CT could well be added as an important element of physics reasoning, at least in experimental physics, where we must use computation regularly, including creative design of algorithms, and debugging. This could be added as front matter of the TSM, and then brought back in the activities, and in the practical work, errors and uncertainty, as well as the ICT sections. In the individual investigation, it could also be possible to include CT dimensions, although this would need to be embraced as an explicit value by the DP Physics course.

In general, to add any aspect of computation would entail an overt commitment on the part of course developers to infuse computation into the course. This would mean adding an assessment priority as well, which obviously is a major commitment. We do not see much room for computation to occur, and yet we recognize that within the discipline of physics, and the many disciplines to which it connects, computation is quite relevant. It would be a good idea to engage course leaders in this discussion. In the meantime, there is opportunity to help teachers recognize the importance of CT by making it explicit within the course aims, and develop curricular projects, internal and external assessments where these sub-skills were clearly part of the learning. This would not be easy for instructors and would require some clear examples.

It would be straightforward to reinforce the introduction of DT into the language of problem solving, by introducing some kind of coverage rubric for the teacher, where the dimensions of DT were explicitly mapped onto these activities. DT could be added as an important element of physics reasoning, at least in experimental physics, where we design apparatus and experiments, critically interpret data, etc. Adding this in the front matter of the TSM, and then bringing it back in the activities, and in the practical work, errors and uncertainty, and ICT sections. The individual investigation also appears well suited for inclusion of DT dimensions.

With regard to CT, the most likely place to add any emphasis would be in the Measurement and evaluation, as well as Engineering Physics.

Perhaps the most straightforward CT dimension to incorporate would be that of *Problem Formulation*. To help the instructor identify such connections, this could be emphasized in the TSM front matter (e.g., problem formation and decomposition, symmetry solutions, etc.). There is plenty of CT in physics problem solving, but instructors would need to make an effort to bring these into the course. It would be important to make an explicit connection to problem formulation as an aspect of CT. The Group 4 project, which is inherently collaborative. Weakness would be that the activities are fairly cut and dried, without room for problem decomposition, iteration, etc. Within the current activities, there is some implicit formulation, decomposition and algorithmic thinking, but this could be strengthened by drawing attention to this dimension and asking teachers to try to work it into their designs.

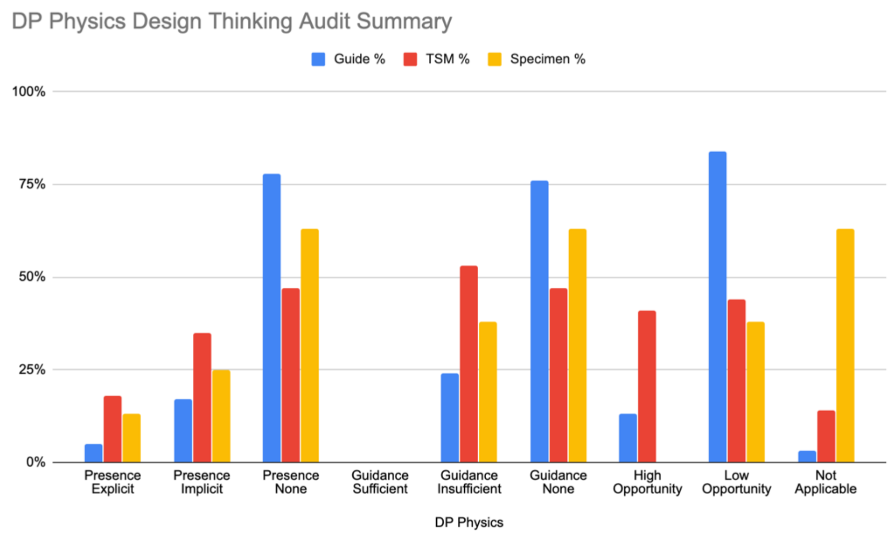


Figure 18. Coding of Design Thinking for DP Physics Documents

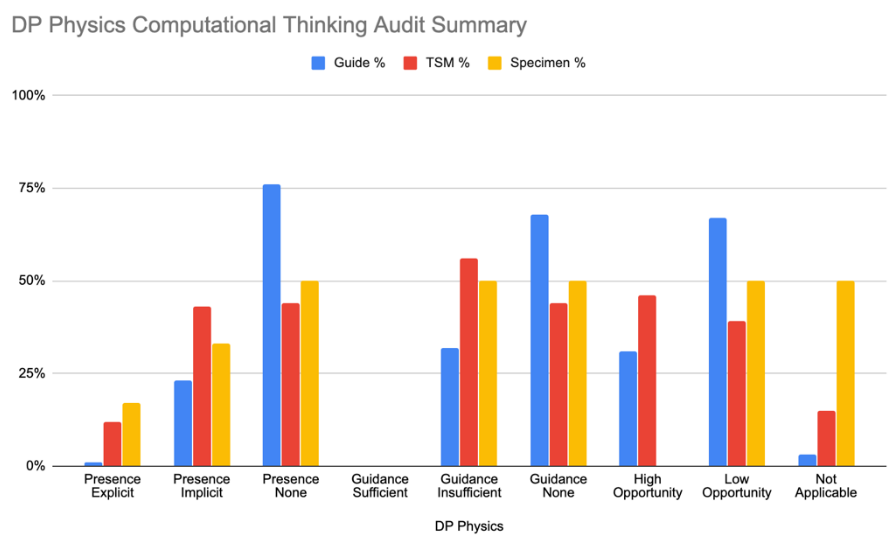


Figure 19. Coding of Computational Thinking for DP Physics Documents

2. DP Geography

This course again contained ample opportunities for making strong connections to both DT and CT. The Guide, TSM, and Specimen Exams all make explicit the expectation that students work with real-world and open-ended problems. The "possibilities" theme in the Guide links well with the *Creativity* dimension of DT. Creative thinking is also implicit in the TSM. Although the Guide has limited links to the *Collaboration* and *Iterative* dimensions of the design cycle, the TSM clearly expects students to work together through multiple cycles of reasoning and expects teachers to observe students' thinking process and provide feedback.

With regard to CT, The DP Geography Guide has a strong emphasis on patterns, interactions, and systems, which are aligned with the *Pattern Recognition* dimension. There is also a reasonably high connection in the learning goals to the *Abstraction* dimension, with related themes such as modeling, projection, predication, testing hypotheses, alternatives, carrying capacity, estimates, as well as representing data for communicating information. The nexus activity in TSM embodies *pattern recognition, decomposition, and iteration* very well. The Specimen Exam also has a number of links to pattern recognition and abstraction.

Some aspects that were noticeably weaker were the lack of links that might easily be included. The *Collaboration* dimension of DT is only mentioned in the internal assessment section and is limited to part of the investigation process (e.g., students are required to complete their reports individually). There is very little link to the Iterative dimension of design. As for evaluation, the internal and external assessment are focused on analysis and argumentation, without much emphasis on design-related skills. The nexus activity in TSM touches on all aspects of DT, but does not directly involve students in designing or thinking about solutions, products, or services. The Specimen Exam does not evaluate any DT dimensions. With respect to CT dimensions, the Guide only has a few themes such as "hierarchies", "describe methods used for information and data collection" which are loosely related to the decomposition and algorithms. No link to these two dimensions is present in the TSM and the Specimen Exam. The *Testing & Debugging* and *Iteration* dimensions are not present in the Guide or Specimen Exam. In the TSM, there is some mention of sustainability and complexity, which are related to Abstraction, but not much on how students can extract the most important dimensions from the model with rich details.

Opportunities and Considerations

With regard to DT, the Guide could explicitly connect DT dimensions with geography themes such as (1) the *Collaboration* dimension and the power theme, and (2) the *Iterative* dimension and the possibility theme. The Guide could also explicitly recommend designing solutions for geography-based problems as a type of internal assessment projects. For instance, the nexus activity in TSM could be better linked to DT if students are required to create solutions such as products or services to help solve the problems emerged from the nexus map. The Specimen Exam could add more questions asking students to evaluate existing solutions, propose new solutions, and create or revise visual representations. Such tasks can elicit students' creative and iterative practices.

With regard to CT, it should be possible to improve connections to the *Decomposition* dimension, where the Guide could provide explicit performance expectations on how students should be able to analyze geographic phenomena at different scales. Similarly, for the *Abstraction* dimension, the Guide could recommend requiring students to represent problems with computational modeling tools. Several places in the guide mentioned GIS as a desirable skill, and advanced use of GIS often requires the careful design of procedure and even basic programming skills to automate repetitive tasks. Finally, the Guide could explicitly connect the possibilities theme with *Testing & Debugging* and *Iteration* dimensions of CT. The nexus activity in the TSM could encourage students to construct more abstract models based on the contextualized model, write down and report their process of building the nexus, and comment on whether their process is systematic and can be proceduralized. Additionally, students can be encouraged to test consistency and coherence within the nexus that they build and systematically address any inconsistent links. The Specimen Exam could add subtasks that require students to tackle a complex problem by breaking it into small pieces, describe the steps they will take to solve a problem, construct models and test the models in multiple contexts, and iteratively improve their models while testing against multiple contexts.

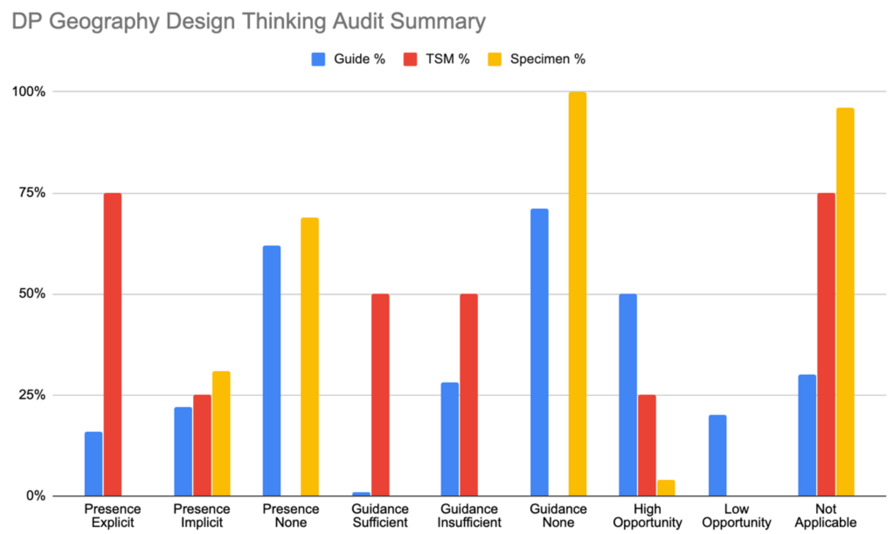


Figure 20. Coding of Design Thinking for DP Geography Documents

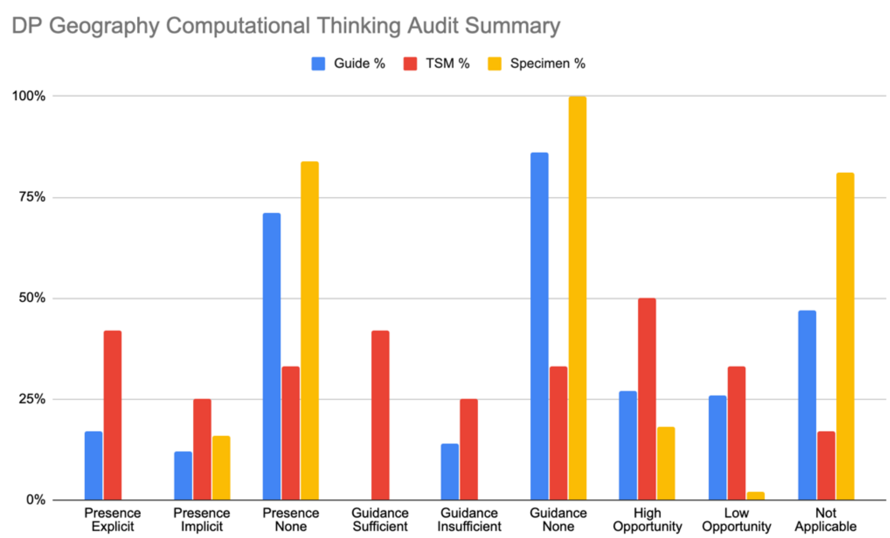


Figure 21. Coding of Computational Thinking for DP Geography Documents

3. DP Computer Science

The DP Computer Science (CS) course has a strong emphasis on the study of CS in real-world, open-ended problems. The internal assessment requires students to work with a real client to solve a real problem. The TSM is also very clear on this requirement. Students have the opportunity to collaborate in their Group 4 project and are encouraged to work closely with their clients and advisors in their internal assessment projects. The course has a fair amount of links to creativity throughout the Guide and TSM. The internal assessment in particular requires students to demonstrate complexity and ingenuity in the use of computing techniques. All sections except the external assessment require students to engage in the entire process of CS-based problem-solving including designing, prototyping and testing.

There were clearly great strengths in the support of computational thinking. The syllabus content elaborated on specific thinking skills (i.e., thinking abstractly, thinking procedurally, etc.). CT is also frequently linked throughout other topic areas such as Abstract Data Structures and Modeling and Simulation. In the Computer Science and Theory of Knowledge section, the Guide even suggests that students discuss to what extent CT is distinct from other thinking styles and to what extent CT can be used to solve problems in other disciplinary areas. This suggestion reflects the intention for students to develop CT as an ability that transfers across disciplines.

With regard to Design Thinking, the DP Computer Science course has a strong emphasis on real-world, open-ended problems. The internal assessment requires students to work with a real client to solve a real problem. The TSM is also very clear on this requirement. However, the external assessment, given its inherent constraints, is limited in this dimension. For example, the case study we audited is based on real-world scenario, but the problems posed to the students are not very open-ended. The course also emphasizes creativity throughout the Guide and TSM. The internal assessment in particular emphasizes demonstrated complexity and ingenuity in the use of computing techniques.

There were several places where we saw the possibility of improvement. First, while students are encouraged to collaborate with their clients and advisors in the Group 4 project, they are not allowed to collaborate with peers in the internal assessment for the sake of accountability. The external assessment also does not present much collaboration opportunity. We recommend an increase in time allocated to Group 4 project and inclusion of teamwork as a part and a criterion of internal assessment. Students can play different roles in each other's projects but still be responsible for their own projects. In several syllabus topic sections, the guide could emphasize that a thorough understanding of CS content such as computing resources and data structures is the foundation for creation of innovative solutions. Another opportunity is the modelling and simulation section, which are essentially creative practices because modelers represent the world by defining variables and relationships.

The Web Science section is about web design, but there is limited description of the design aspect. In the Markbands, it appears that students are allowed to conduct extensive research. We recommend that the markscheme reward students who respond with creative and more cutting-edge solutions. The guide requires students to engage in the entire process of CS-based problem-solving including designing, prototyping and testing. The internal assessment and TSM present the stages of development including "planning, designing, testing, and implementing the solution". This seems to be in line with conventional "waterfall development" workflow and it's unclear the minimal number of iterations students should go through. We recommend modern agile workflow or similar approaches that emphasize user-centered design, frequent testing, and reflective process.

Opportunities and Considerations

The external assessment, given its inherent constraints, has limited links to DT. For example, the case study we audited is based on real-world scenario, but the problems posed to the students are not very open-ended. As for collaboration, the time allocated to Group 4 project seems limited, and there is no opportunity for collaboration in the internal assessment, presumably for reasons of accountability. The external assessment does not present much collaboration opportunity either. The internal assessment and TSM present the stages of development including "planning, designing, testing, and implementing the solution", which are in line with conventional design workflow (i.e., waterfall development), although it is unclear the number of iterations that students are expected to go through.

The internal assessment explicitly links to *Algorithms*, *Testing & Debugging*, and *Iteration*, but has little explicit link to other CT practices (i.e., *Pattern recognition, Decomposition,* or *Abstraction*). The external assessment, given its inherent constraints, only has a few implicit links to *Pattern Recognition* and *Algorithms*, as the computer forensics case study requires students to identify patterns and anticipate the effects of steps taken to interrogate the evidence (e.g., switching off computers may accidentally erase important evidence).

Overall, the Group 4 project appears to be one area where CT and DT could be strengthened, including the possibility of adding teamwork as a part and a criterion of internal assessment. For example, students could play different roles in each other's projects but still be responsible for their own projects. In several syllabus topic sections, the guide could emphasize that a thorough understanding of CS contents such as computing resources and data structures is the foundation for creation of innovative solutions. Another opportunity is the modelling and simulation section, which are essentially creative practices because modelers represent the world by defining variables and relationships. In the external assessment mark bands, it appears that students are allowed to conduct extensive research. We recommend that the markscheme reward students who respond with creative and more cutting-edge solutions. Additionally, we recommend modern agile workflow or similar approaches that emphasize user-centered design, frequent testing, and reflective process.

Curriculum designers might consider revising the definition of CT to include the dimensions of *decomposition* and *iteration*, in line with our literature review. Additionally, the course could frame CT as a way of thinking that can be used to enhance problem solving in other disciplines. For example, in the Modelling and Simulation section, students could explore specific mathematics and science topics that rely on modelling and simulation. For external assessment, consider presenting students with scenarios and recorded observations and asking them to draw inferences from the raw data and outline the steps they will take to investigate the case. These tasks require students to demonstrate pattern recognition, decomposition, and algorithmic thinking abilities.

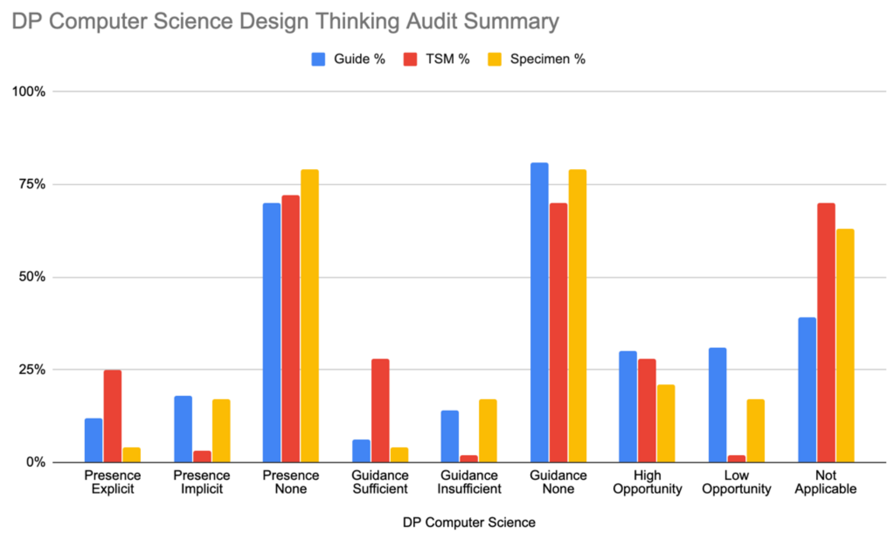


Figure 22. Coding of Design Thinking for DP Computer Science Documents

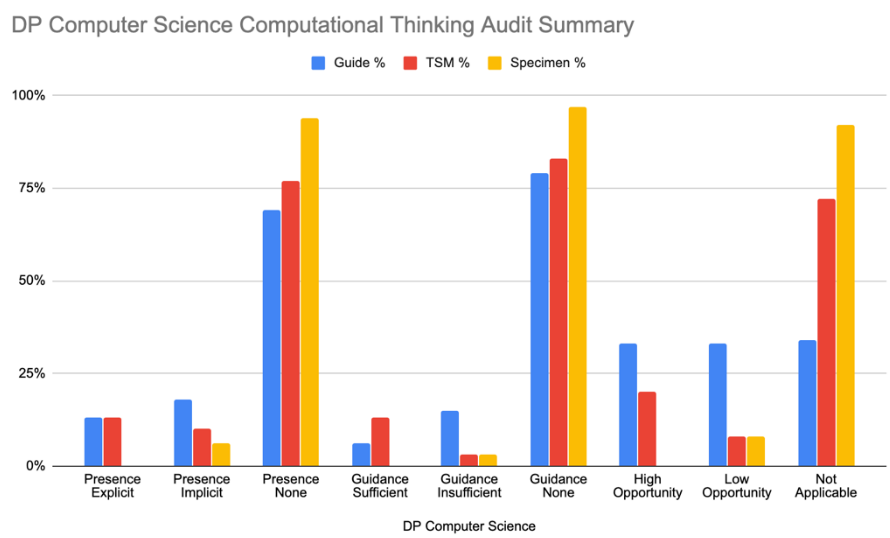


Figure 23. Coding of Computational Thinking for DP Computer Science Documents

4. DP Design Technology

Overall, this course integrates DT very well, not surprisingly, with many opportunities for students to engage in DT and for the teacher to make explicit connections to DT. Throughout the Guide and TSM, connections to real-world problems are clear (especially in the TSM). The design project is an excellent example of a project in which students need to engage in nearly all the DT dimensions at a high level. The Exam Papers 2 & 3 do a nice job of providing students with opportunities to apply DT to address real-world problems. With regard to CT, the dimension of *Decomposition*, *Algorithms*, and *Testing & Debugging* are all well represented in this course, and we see opportunities for strengthening the connections between design and computational thinking (for example, in topic 3 -- Models). While the TSM does highlight activities that can be connected to CT, these connections are rarely explicit. For example, the need to break down processes and strategies (*Decomposition*), how students implement these strategies (*Algorithms*), and the explicit need for *testing and debugging* of design are all core to the design process, but are not explicitly connected.

While the course is clearly centered on the design cycle, there seems to be a need for more opportunity for students to iterate on their designs. At least from our reading of the course materials, it seems like students mainly just engage in a single design pass (i.e., they do not evaluate and revise). Another potential issue in the TSM is that there appears to be a lack of collaboration in this design work, despite the focus on its importance in the theoretical parts of the guide. From our reading, it seems like there are opportunities for students to work together to come up with design solutions, but the teachers will need to dedicate time for such collaborative activities. In the Exam specimens, there was a clear absence of iteration as well as collaboration, although these would be understandably challenging, given the need to assess students individually.

With regard to CT, we noted many possible connections between CT and the course materials, although most of these were not made explicitly. For many of the CT dimensions, it seemed like there would need to be a concerted effort to build in some connection. For example, the dimension of Patterns would be seemingly relevant to design, but is nowhere present in the materials we audited. In the exam, there are many questions where the CT dimension of *Decomposition* is required, but this is not treated as being connected to computational thinking. And most of the other CT factors are given very light attention (if at all). This is largely due to the fact that Paper 1 (and to a lesser extend Paper 2) are more about specific factual recall that nuanced application.

Opportunities and Considerations

In the Guide, it was not clear to what extent the overarching goal is to have students learning about the different processes and approaches, vs. really putting those processes into action (i.e., in the form of designs they create). While it is clear that students do engage in actual design work, any strengthening of this process – particularly in the addition of collaboration and iteration, as well as iteration, would serve to reinforce the DT and CT connections. It could also be beneficial to add some treatment of these elements into the examinations – having students consider the value of collaboration and iteration.

With regard to CT, the guide, adding in additional opportunities for students to use modeling software would provide them opportunities to use and understand the role of CT in their designs. It could be very helpful for teachers to stress the dimension of *Decomposition* as a key element across the design curriculum. Given the design-focused nature of the course, teachers should consider taking the time to make clear connections between DT and CT whenever there is an opportunity. as this would make valuable cross-cutting connections. For example, there is the potential to connect some CT principles that are currently missing (e.g., *Patterns* or *Abstractions*) in the final project. To support teachers, it would help to make the motivation and the criteria for such connections more explicit. Teachers could point to Abstraction and Patterns as broad design principles, for example. In the Exams, it is possible to introduce more CT dimensions, such as by adding questions that require reasoning about and application of design processes. These expectations would need to be made clear in the examination materials, as well as the TSM.

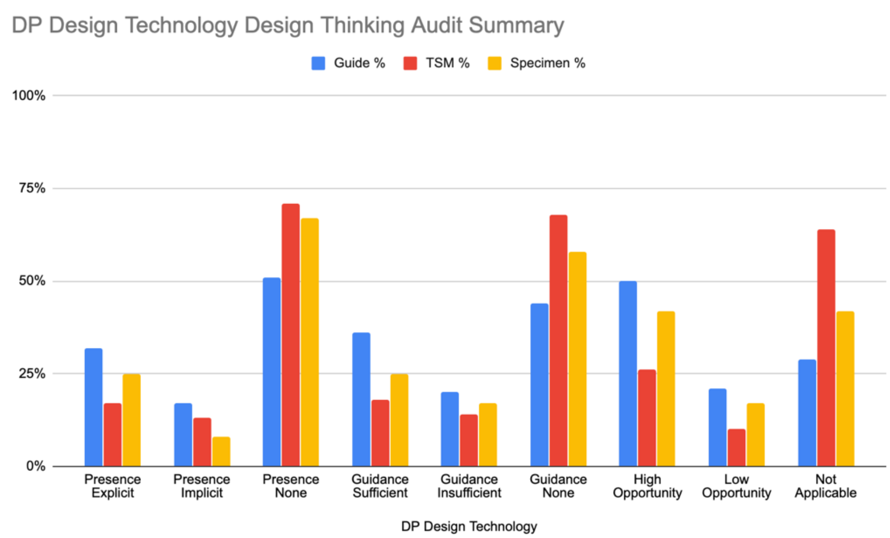


Figure 24. Coding of Design Thinking for DP Design Technology Documents

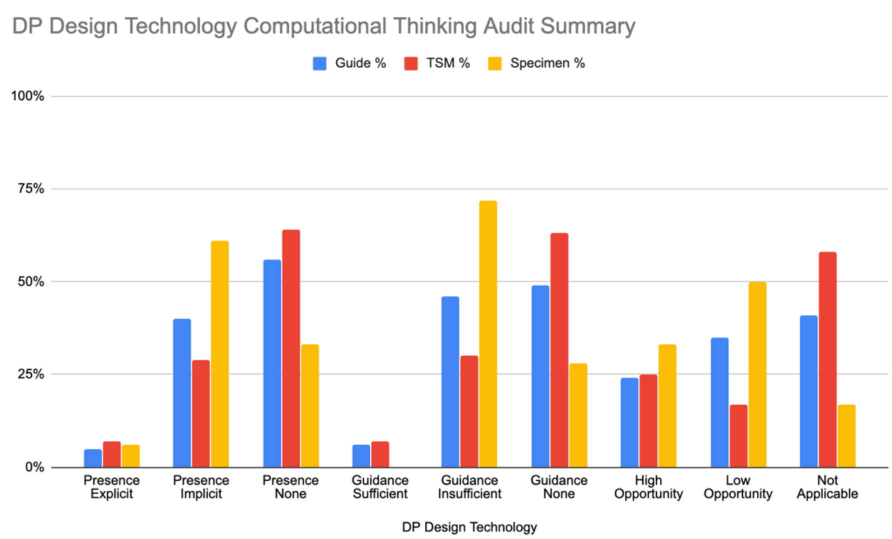


Figure 25. Coding of Computational Thinking for DP Design Technology Documents

5. DP Mathematics

The DP Mathematics: Applications and Interpretations course Guide places a strong emphasis on real-world applications of mathematics. The "real-world" theme is running through the entire guide and the TSM. For instance, in the Syllabus content section, each topic area is framed as tools to solve real-world problems. The "open-ended" theme appeared much less frequently, only in "Assessment objectives" and "Methods of assessment" sections. Collaboration is emphasized in the internal assessment. Creativity is a salient theme in the guide, especially in the Nature of Mathematics section. Also, in the Mathematics and creativity, activity, and service (CAS) section, the Guide is explicit about the connection between math learning and CAS projects. In the Aims section, "creative thinking" is explicitly part of one of the aims. The Internal Assessment section also used "thinking creatively" as an indicator for personal engagement, one of the internal assessment criteria.

The Guide mentioned pattern recognition a few times. Pattern recognition is also an integral part of mathematical modeling, a strong emphasis of the Guide, thus we considered the Guide to have fairly strong link to the pattern recognition dimension. The Guide also has a strong emphasis on abstraction. The terms "mathematical modeling", "model the real world", "applications", "abstraction", and "generalization" frequently appear throughout the guide, especially in the Syllabus content section. The Guide emphasizes two different aspects of algorithms. One is about understanding and performing mathematical procedures and algorithms such as calculating statistical measures and graph theories. The other is the use of technology to perform math procedures. This aspect is implicitly linked with the algorithms practice because effective use of technology requires creating mathematical procedures and determining which steps can be automatically by using technologies. The TSM also explicitly and implicitly link to several dimensions of CT including pattern recognition, decomposition, abstraction, and algorithm. The activity examples (i.e., Voronoi Diagrams, Shooting Arrows, Overloading Lifts, and Feel for Data) demonstrate clearly how to engage students in these computational thinking processes. In the Specimen Exam, the "Two IB schools" question and the markscheme are implicitly linked to the Pattern Recognition dimension as students are required to identify appropriate statistical tests for the problem. The "Brown and black squirrels" question is implicitly linked to the Abstraction dimension because students are asked to provide a general solution.

The Guide's emphasis on math modeling is closely linked with this aspect of DT because math modeling is an iterative process of designing mathematical representations of real-world situations. However, there are only three sections that mention the iterative cycle. The assessment section described the role of collaboration in the internal assessment and reflection, which is an important part of creative thinking, as one of the assessment criteria. However, the other three DT dimensions have no presence in the assessment section. In the TSM, there is only one explicit link to the collaboration dimension in the Approaches to Teaching and Learning section. For the Creativity dimensions, there are only a few implicit links. The Iteration dimension is mentioned only in the Mathematical Modeling section. In the Specimen Exam, the two questions reviewed are both contextualized in real-world situations, but the questions are very structured and close-ended for the purpose of assessing specific learning outcomes.

There is little mention of the decomposition dimension. Testing & Debugging and Iteration dimensions are only implicitly linked as integral parts of the mathematical modeling process. In the TSM, there are only a few explicit links present for the Testing & Debugging and Iteration dimensions. In the Specimen Exam, links to CT dimensions are very limited.

Opportunities and Considerations

The Guide could stress the "open-ended" theme by highlighting it throughout the syllabus content section. Despite the previously mentioned strengths, there are only a few mentions in the syllabus content section. Many of them are brief and provide insufficient information. The guide could be strengthened if the Syllabus content includes more detailed guidance on the creative process involved in using mathematics to solve real-world problems. Given that math modeling provides a natural link with design thinking, the Guide could stress the iterative nature of math modeling and the role of modeling in design throughout the syllabus content. In the TSM, there are many opportunities to integrate Design thinking as the course was created to develop students' competencies of using many mathematics to solve real-world problems. In particular, mathematical modeling and using technology are practices that can engage students in creative thinking and iterative processes. It is less clear how the collaboration dimension can be naturally incorporated into the course, especially for the internal and external assessments.

The Guide could recommend the use of programming languages, especially novice-friendly and domain-specific language (e.g., R and MathLab) to promote the development of algorithmic thinking. Although the guide mentioned very little about decomposition, however decomposition is a necessary step in mathematical modeling when the problem is too big and open-ended. The guide could further elaborate on the mathematical modeling cycle and highlight the importance of the ability to handle complexity with systematic decomposition. Additionally, the Guide could make links to the Iteration and Testing & Debugging dimensions in the syllabus content section, especially in the "Guidance, clarification and syllabus links" area, to describe how these practices can be implemented in specific content area. As described above, many CT dimensions are already explicitly and implicitly present in the TSM. The TSM developers may consider labeling certain parts of the TSM with CT terms. Also consider expanding activities to elevate student experience from using computing tools with full guidance to independently creating solutions and leveraging computing tools. Unfortunately, there is limited opportunity to integrate CT in the Specimen Exam due to the closed format of the exam.

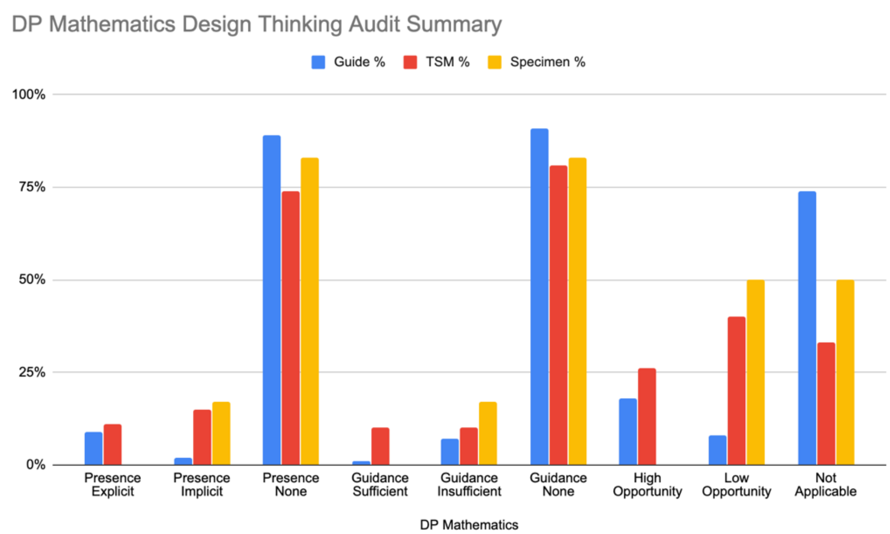


Figure 26. Coding of Design Thinking for DP Mathematics Documents

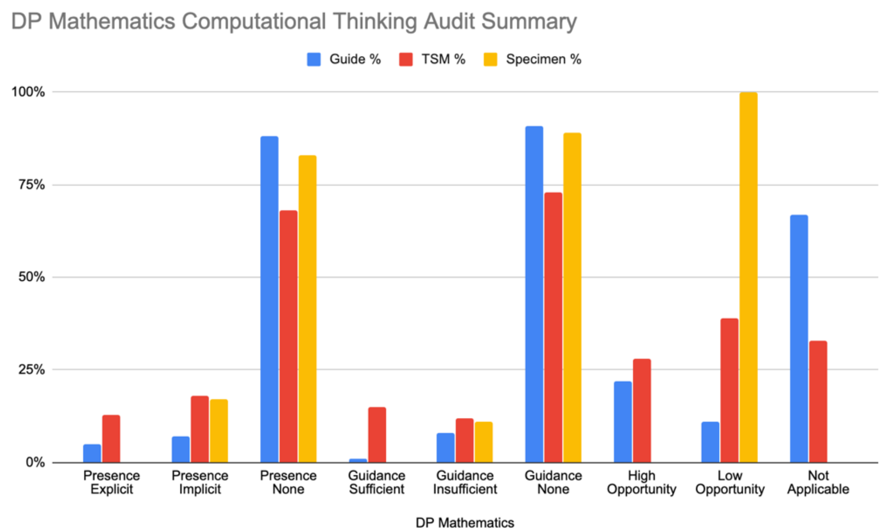


Figure 27. Coding of Computational Thinking for DP Mathematics Documents

6. *DP Chemistry*

Chemistry is a domain in which there are clear applications to real world problems and clear connections to design and computation. However, given the focus on coverage of content, this course had limited space or time for such activities. While there is a strong component of experimentation, this does not include any use of computation which is common in the field of chemistry, but not very common at all in K-12 treatments of the domain. In the Group 4 project, practical work offers several opportunities for integrating DT in the course, as it focuses on a real-world application and gives the students the opportunity to engage in thoughtful design and iteration. Thus, there are some strong connections to real-world problems that could serve as a foundation for emphasizing DT and CT connections. With regard to computation, this could be achieved whenever students are engaged in looking at or generating data, where we recognized opportunities to engage in *Pattern Recognition, Algorithms,* and *Testing & Debugging*. The dimensions of *Decomposition* and *Abstraction* could also be woven into students' understanding of chemical compositions, compounds, and reactions. However, we recognize that this would take some effort on the part of curriculum developers, and real creativity on the part of teachers. We see this as a real challenge for this course, but also potentially a productive one that could serve to make the material more relevant and engaging.

One issue is that much of the work - especially in the experiments - seems to leave little freedom for the students to be creative, with students mostly conducting very strictly defined investigations. This was noticed in our coding of the guide and the TSM, which focused more on students' acquisition of concepts and facts than on any process of design or exploration. The specimen exam was focused solely on capturing students' understanding of chemistry (i.e., rather than explorations or adaptations). At present, we found no opportunities for assessing DT or CT within the exam. With regard to CT, there were some connections made to some dimensions within the Guide, but it seemed that teachers would be challenged to weave these connections into their instruction. It would help to make these connections more explicit.

Opportunities and Considerations

We recognize an opportunity to engage students in DT by opening up some of the experiments – to make them less formulaic (i.e., with fully explicated outcomes) – perhaps by allowing students to pose their own specific questions and design some experimental approaches. This could allow for some inclusion of design within the narrative of chemistry experiments. In the exam, the inclusion of more open-ended questions in which students must consider how to apply chemistry to a specific proposed problem would allow teachers to assess students' ability to think flexibly and conceptually about chemistry principles and practices.

While there are implicit connections to some dimensions of CT, teachers would likely need more guidance in recognizing such connections, making them relevant to students, and ideally in engaging students in some form of computational practices or reasoning. Based on our own prior experiences as learners and teachers of chemistry, we understand how this course is particularly challenging for introductions of CT – even of specific dimensions like *Decomposition, Algorithms, or Abstraction*. We understand that such aspects may come in future chemistry coursers (e.g., physical chemistry) or applications of chemic al engineering, and wonder about including some aspect of "Chemistry career connections" – where students can be exposed to other forms of problem solving and reasoning within this important STEM discipline.

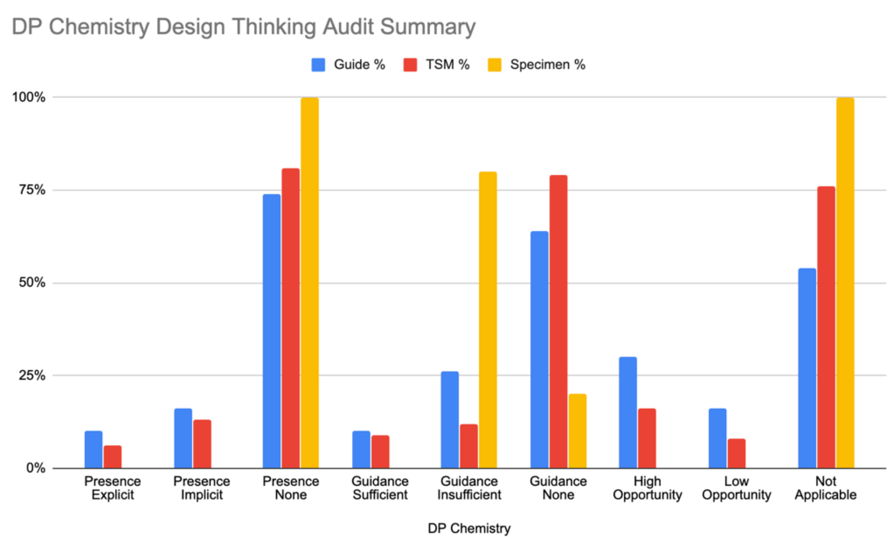


Figure 28. Coding of Design Thinking for DP Chemistry Documents

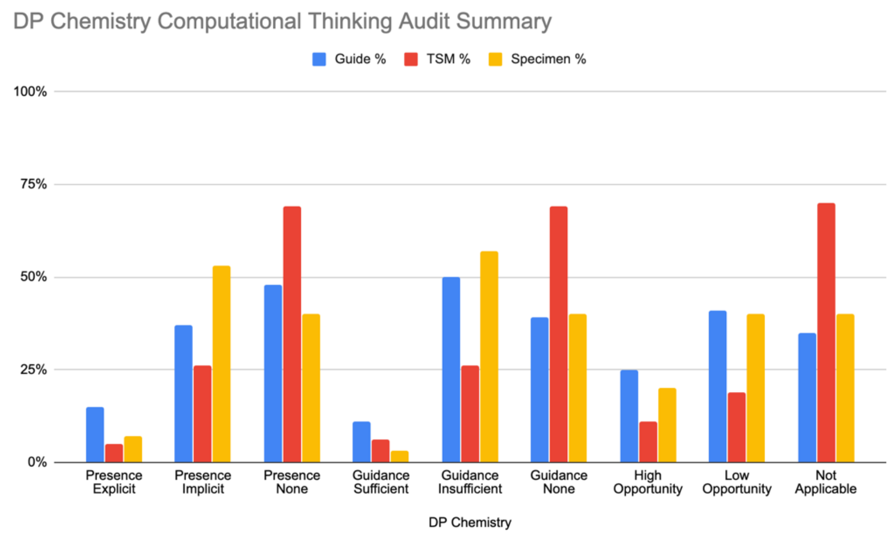


Figure 29. Coding of Computational Thinking for DP Chemistry Documents

The Middle Years Programme

1. MYP Math

The Guide and TSM explicitly link to the real-world, open-ended problems, which is an important dimension of DT. Over half of the questions in both Specimen Exams are explicitly or implicitly grounded in such problems. The Guide emphasizes mathematical communication, a central practice in *Collaboration*, consistently throughout all sections. There are also explicit links to collaboration in the CALP examples and the MYP unit planner. The *Creativity* dimension of DT is also made explicit in the Guide's conceptualization sections. Phrases such as "creative thinking" and "design projects" appear in multiple locations within the Guide, and the TSM also makes some implicit links to these dimensions. Regarding CT, the Guide and TSM explicitly link to the *Pattern Recognition* dimension, as do several questions in the specimen exams. The *Abstraction* dimension is also present throughout the Guide and the TSM, and one of the questions in Specimen clearly asking students to extract and generalize rules.

While the Guide does prioritize *Real-world problems*, it does not emphasize the open-ended nature of such problems. Indeed, the example problems provided within the TSM seem very close-ended. The Guide mentions *Collaboration* in the sections on Interdisciplinary learning, but this is not consistently treated in other sections such as the Mathematics skills framework and Assessed curriculum. There is also a lack of elaboration on the *Creativity* dimension of DT in the Guide's Mathematics skills framework and Assessed curriculum sections in the TSM. The Specimen Exam does not have much link to creativity either, due to the closed-ended nature of the questions. Neither the Guide nor the TSM include any emphasis of the *Iterative* dimension of the design cycle, with only a few implicit links.

With regard to CT, there are only implicit links to the *Decomposition*, *Algorithms*, and *Testing & Debugging* dimensions in the Guide and TSM, such as in the use of terms like "logical thinking", "lines of reasoning", "logical structure in order to be followed", "reach a correct solution", mentions of use of technologies, "justifying a solution" and "prove, verify and justify general rules". The *Iteration* dimension has a few implicit links within the Guide, via terms like "applying math in design projects" and "obtain rapid feedback when testing out solutions" (i.e., implying further revision and improvement). The TSM describes a process in which students are asked to perform similar proportional reasoning tasks across slightly varying situations, which makes an implicit connection to *Abstraction* and possibly *Pattern Recognition.*

Opportunities and Considerations

This course has ample opportunity for connections to both CT and DT – particularly given the interdisciplinary nature and central role of design within the MYP curriculum. Teachers could be supported in making these connections through more explicit linkage within the Guide and TSM, even without making the structural changes that might be required to explicitly address them within assessments. For example, the Guide could add "open-ended" as a descriptor in addition to "challenging" and "unfamiliar". The Guide could also add collaboration practices such as "establishing shared vision and goals" and careful listening, when it addresses real world problems. The MYP unit planner in the TSM also presents a great opportunity to emphasize collaboration. To link better with the *Creativity* dimension, the Guide could emphasize creative use of mathematics to solve unfamiliar and complex problems. To link with the *Iterative* dimension of design, the Guide could leverage the mathematical inquiry, mathematical modeling, and using math in design projects, which are all iterative in nature. The TSM's MYP unit planner could suggest an iterative design activity, perhaps based on the cooking activity. To evaluate DT dimensions, the Guide could include explicit phrases in the assessment criteria.

With regard to CT, the guide could emphasize that solving complex problems may require *Decomposition* and also emphasize the roles of computing technology in handling complex problems. The *Algorithms* dimension could be more explicitly linked by suggesting algorithmic approaches to "logical thinking" and communication, and suggesting technologies such as programming environments to empower students to do math work, especially math modeling more efficiently and with reproducibility. This could allow for *Testing & Debugging* and *Abstraction,* which could also be linked by explicitly describing the processes of math modeling, math inquiry, and application of math in design projects.

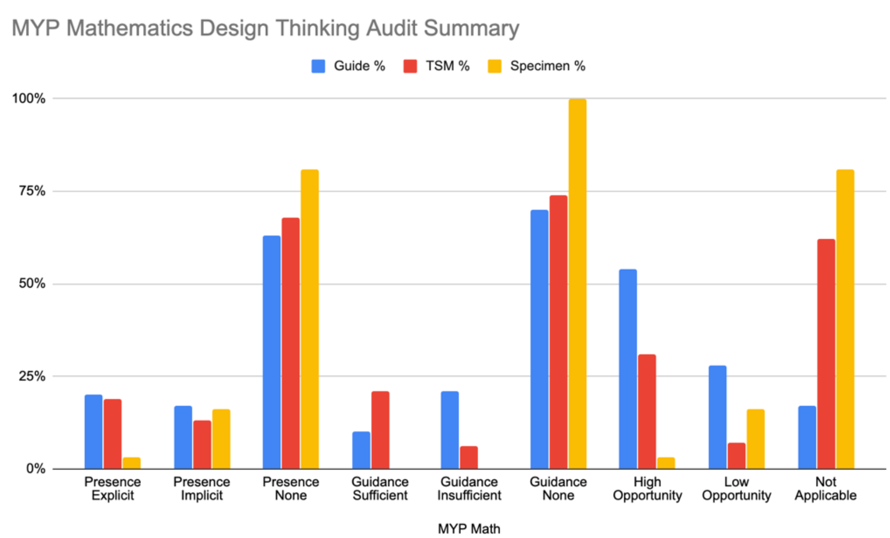


Figure 30. Coding of Design Thinking for MYP Mathematics Documents

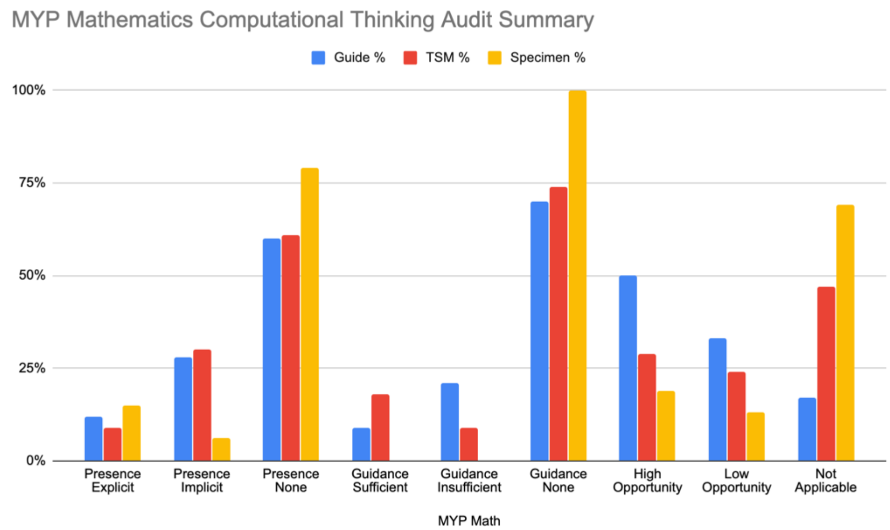


Figure 31. Coding of Computational Thinking for MYP Mathematics Documents

2. MYP Science

The Nature of Science section places inquiry directly at the core of this program, making clear that science is connected to all aspects of life. "Critical and creative thinking about research and design" is also expressed as a central value, as is communication - all of which are strongly supportive of DT. That said, there is no explicit mention of design thinking, nor any place given to it in the Nature of Science section, beyond those early mentions. Collaboration is also mentioned as one of the core dimensions, which is highly consistent with DT, but again, not explicitly connected in the guide. Example 3 (design a piece of clothing) is an excellent assessment, and it certainly engages DT. However, DT is not explicitly addressed in the teacher materials. While ideas such as the Dragon's Den presentation are consistent with DT, these connections are left somewhat implicit, and there is no reference to dimensions of *Collaboration* or *Iteration.* While the specimen exam includes many connections to real world problems, it does not explicitly engage any dimensions of DT such as *Creativity*, *Collaboration*, or *Iteration.*

The overall presence of CT dimensions was quite low - limited mainly to indirect references of *Pattern Recognition*. This could be because MYP science is more conceptual in nature, with no engineering science or computational methods, so that *Algorithms* and *Decomposition* are not highly relevant. In general, there is very little treatment of computation within the Key or Related concepts, or the objectives. In the assessment criteria, there is some mention of data and evaluation, but never in terms of computation, algorithms, or abstractions. Example 3 is a design-oriented task, in which students work on an experiment that produces data, which they use as a basis for design decisions. There is some potential for CT here, but at present there is no clear treatment of *Decomposition* or *Algorithms*, nor *Debugging* or *Iteration*. So, while there is likely some implicit CT within this example, the lack of explicit attention makes it challenging to ensure there is effective engagement within the dimensions of our working definition. While the items about water clocks clearly engage some CT, including algorithmic thinking, and certainly problem formulation and decomposition, and may even serve to assess engagement within these constructs. However, these items fall short of engaging computational dimensions such as *Algorithms* or *Testing & Debugging*.

Opportunities and Considerations

There is great opportunity for connecting to DT and CT, as a result of the interdisciplinary nature of MYP, and the MY projects in particular. Given the high value placed on real world problems and connections, it should be straightforward to highlight DT within various sections of the guide, clarifying for teachers that such thinking is a priority and aim of instruction. In the "Teaching and Learning through Inquiry" section, for example, an explicit connection could be made between DT and CT, adding these into the Key concepts. Because the Teaching through Inquiry section isn't clear on *how* inquiry would be used to help students achieve understanding of these concepts (e.g., in Systems, Change, Interactions), DT and CT could be emphasized as one prominent mechanism, which could help give meaning to the inclusion of *Collaboration*, *Testing & Debugging*, and other elements of CT and DT that are common to science inquiry learning. In the "Inquiring and Designing" objective, the treatment of design is limited to the design of a method. But this could also be a great place to add design more broadly, e.g., of apparatus, or solutions to physical problems. Because there is an explicit objective of inquiry design, this should be a clear place where greater connections could be made.

To strengthen the presence of CT, the Guide and TSM could include some examples where computational environments were employed within inquiry – perhaps in the Processing and Evaluation, sections, or Inquiring and Designing. In the "Teaching and Learning through Inquiry" sections, there really could be a connection to DT and CT, but they don't seem to fit into the Key concepts - and would need to be emphasized within the related concepts section, e.g., as a means of understanding Key concepts. Elements of CT could be added into the learning progression and the assessment criteria to help support the use of inquiry as a means of achieving the learning goals. One approach to integrating CT more deeply would be to allow iterative improvement of student designs, based on data. By asking students to reflect more on the algorithms and specific computational approaches they used, and how those support their designs, we can promote both CT and DT.

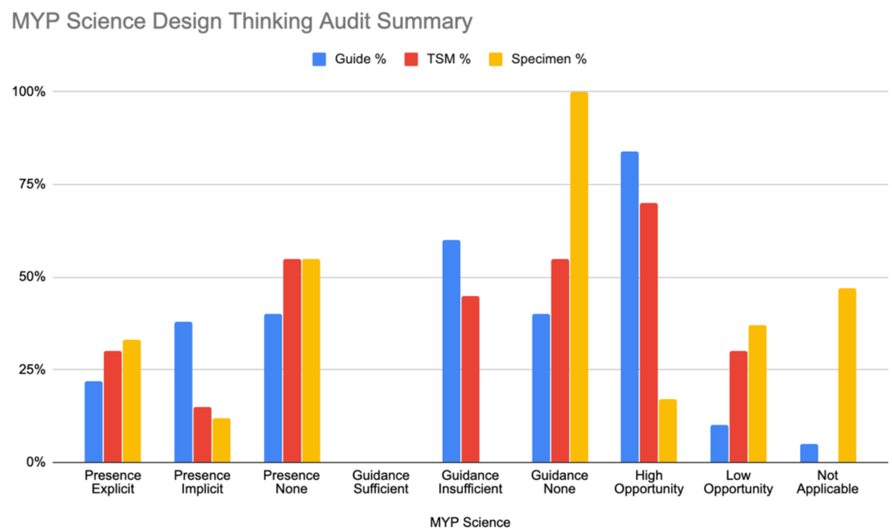


Figure 32. Coding of Design Thinking for MYP Science Documents

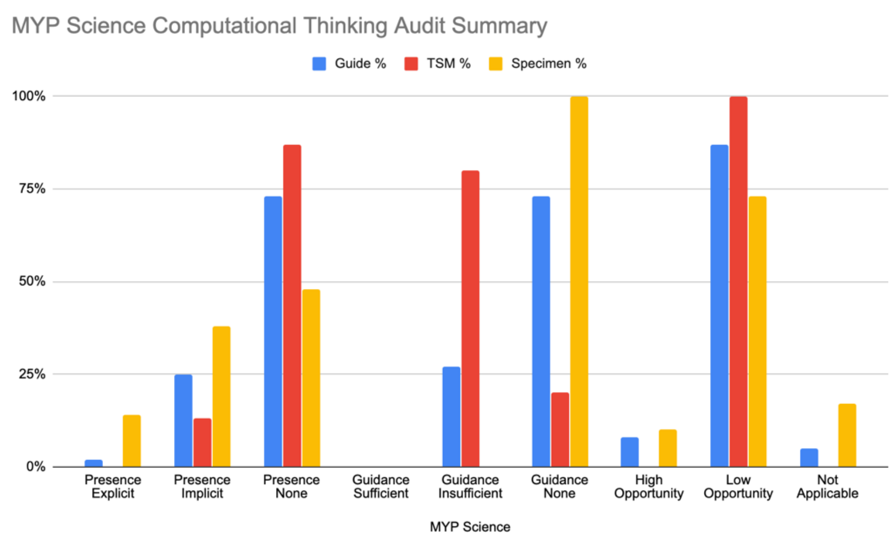


Figure 33. Coding of Computational Thinking for MYP Science Documents

3. MYP Design

We recognize that design and interdisciplinary thinking are at the heart of the MYP, and this course is one that strongly supports both DT and CT in many of their dimensions. In the guide, the connections to DT are clear and present throughout. Students are tasked with solving real-world problems that are sufficiently open-ended to allow them some agency in coming to their own unique solutions and even design processes. This approach is supported by the TSM, which describes how students can go about addressing these problems as creative, challenging, and interesting learning experiences. The specimen exam for this course was exemplary in its grounding in real-world problems where students have some creativity in developing their own unique solutions. This assessment is well suited to engaging (and assessing) DT across many dimensions.

With regard to CT integration, there are very few connections to the dimensions of *Patterns* and *Abstractions,* even though these would seem to be quite relevant to design, as well as *Testing & Debugging* and *Iteration*. There are some clear implicit connections within the "Progression of the Learning" section. where students are required to decompose their design specifications with more detail and granularity between Y3 and Y5. We recognized a potential connection here to the *Testing & Debugging* dimension which could be rein forced across the three years. The TSM outlines how students must decompose their design requirements and processes, and then put them into actionable form – which implicitly connects to the *Algorithm* dimension. The Guidance sections make it clear that there is a role for *Testing & Debugging*, but the importance of *Iteration* is not directly expressed. The specimen exam does provide some opportunities for CT in the *Decomposition*, *Testing & Debugging,* and -- to a lesser extent -- the *Algorithm* dimensions.

There was a notable lack of any strong role for *Collaboration* within the Guide and TSM, although collaboration was stressed as a value within the "Nature of Design" section of the guide. Similarly, while iterative improvements or design revisions are described, they appear as more of a conceptual value than something students actually put into use.

Opportunities and Considerations

The course clearly emphasizes design thinking, with many excellent opportunities in evidence throughout the audited materials. The two aspect we saw that could possibly be strengthened were Collaboration and Iteration, and we suspect these elements are actually present in many teachers' enactment of the course. In a section above, we addressed our research question (how IB teachers are incorporating DT and CT), examining survey responses from course instructors which includes examples of how they incorporate DT and CT. In this course, despite its dedication to such forms of thinking, we found that many teachers expressed the need for more explicit guidance. It could be helpful to provide some or all of the dimensions of our DT working definition, including *Collaboration* and *Iterative Improvements*, so that teachers have a clear expectation about how to promote DT.

With regard to CT, there are many ways in which computation occurs regularly in the process of design, including digital layout and prototyping, modeling and many exciting new forms of robotics and microprocessing (e.g., Arduino). The rise of makerspaces has engaged students in many forms of computational thinking, as they learn to "hack their lives" and embed computation into the world around them. We suspect that MY instructors do regularly engage in such practices within their courses (e.g., in design projects), but again, some explicit reference to computation generally and CT in particular would be helpful. Having students think about higher-level practices and rules for design could be a way to integrate more *Abstraction* into the curriculum. In the guide, many of the CT criteria could be more explicitly connected to the course (e.g., *Decomposition* and *Algorithms*, as well as *Patterns*), but the guide needs to provide guidance about the nature of such connections and how to include them as elements of the course. We feel that the addition and emphasis of a computational aspect to this course could serve to strengthen both DT and CT, as well as the intersection of the two. The exam could possibly include some opportunities for students to work with data or simulations as part of a design process.

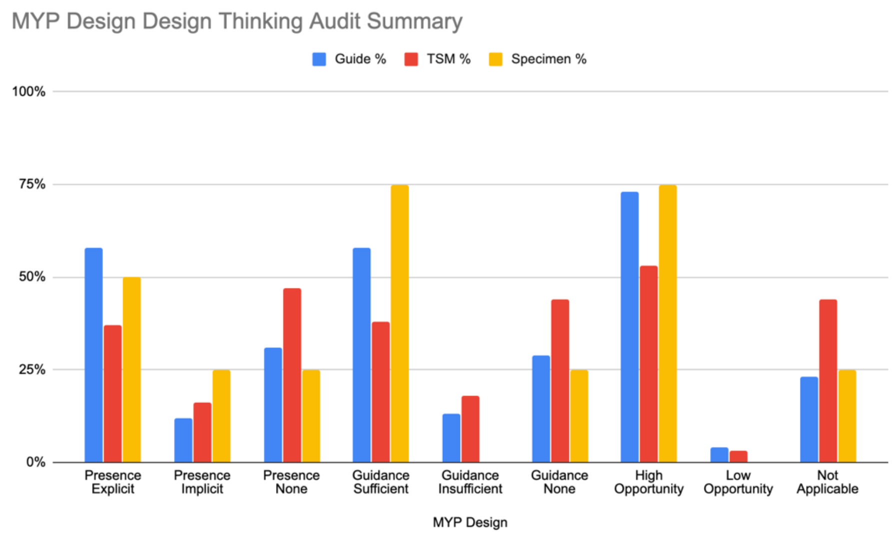


Figure 34. Coding of Design Thinking for MYP Design Documents

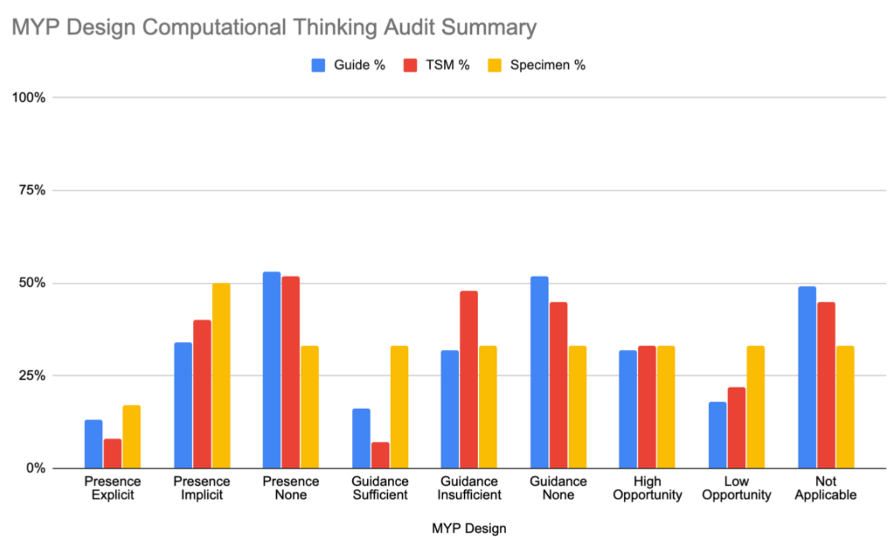


Figure 35. Coding of Computational Thinking for MYP Design Documents

4. MYP Individuals and Societies

We found a strong emphasis of critical thinking in this course, which is deeply connected to design, as is the emphasis on investigation and interdisciplinary connections. Given the interdisciplinary and design-oriented nature of the overall MY programme overall – particularly in the MY Project, it seems that design could be deeply connected with topics of Individuals and Society. The fact that the curriculum is meant to be organized around local culture and community lends itself to such personally relevant topics and connections. That said, there was an overall lack of explicit connection made to design and computation, and the lack of guidance about how to position those major social movements (design and computation) within the course. Course materials could be improved in supporting the teacher to build such connections. Example 6 (design a new continent) is a wonderful activity, that definitely connects design thinking -engaging some variables (landforms) and critical thinking. However, the use of this item to engage design thinking would need to be supported by stronger guidance. Thus, while there were excellent connections to real world problems and creativity, there was a lack of explicit treatment of design as a formal approach, with no treatment of the value of *Collaboration*, for example, nor *iterative improvement* of design. The action plan for urban regeneration is fundamentally a design problem, and this could be explicitly emphasized.

Computational thinking was notably absent from any course materials, for obvious reasons. While there are some aspects of quantitative reasoning in such items, such as *Pattern Recognition*, *Formulation* and *Decomposition* of the problem, there are no explicit connection to CT there is no explicit connection. The MY project is also a clear opportunity to connect CT within this course. As noted above, Example 6 is a great task for design, but not much for computational thinking. Thus, while we recognize potential connections, they may be best to leave as implicit and kept in conjunction with design-oriented tasks.

Opportunities and Considerations

One opportunity for this course would be to help students understand the rise of the Internet, the dot com era, and the design culture that is now in full force. There is really nothing bigger confronting them than their future workplace and associated "climate action/reaction economy". Design would be at the forefront of all such movements, and hence could be extremely relevant in any discussion of individuals and society. Hence, it may be as much in the topics chosen, to address current events and social studies, as it is in any specific aims or objectives. Teachers could build connections to key social movements and elements in society and individuals' lives. Possible curriculum ideas would be to examine some key designs or innovations in terms of their impact on society, like the iPhone, or the recent e-scooters or Blixi bikes. Marshall McCluhan could be introduced as a visionary thinker, or Alvin Toffler -- both of whom address the importance and even centrality of design. Don Norman's book *The Design of Everyday Things* could be a potential resource as well, at least in the Year 4 and 5 courses. Adding design as an explicit goal for instruction may be a bit of a stretch, but it could be a good start to help teachers recognize the connections to design and to encourage them to emphasize DT and CT.

With regard to CT, one opportunity could be to include the role of Computation and digital and social media within society, as vital social movements and dynamics of change. Students could consider parallels between the industrial revolution and the information age, where the power of computation has dramatically boosted the economy and changed lifestyles in many nations from 1990 onward. They could also try to understand the rise of automation and machine learning as new movements, as well as the role of social media and advertising on the internet. "Fake news" and the need for critical thinking could further engage such discussions, as simply understanding some of these ideas could be critical to students' own identity formation, schooling decisions, and engagement in CT and DT.

One way to integrate CT more deeply within the curriculum would be to allow iterative improvement of student design, based on data, which would also strengthen the presence of DT. Students could be asked to reflect on the algorithms and specific computational approaches they employed. New assessment items could be designed that touch on computational geography, machine learning, modeling (e.g., of climate, species decline, etc). These would need to be added into the curriculum, and then assessed, accordingly, which would clearly require some extended time to implement.

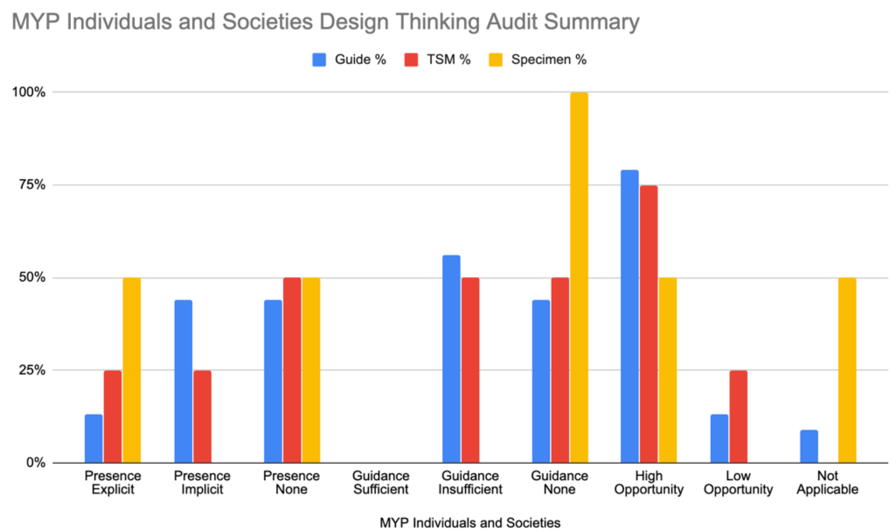


Figure 36. Coding of Design Thinking for MYP Individuals and Society Documents

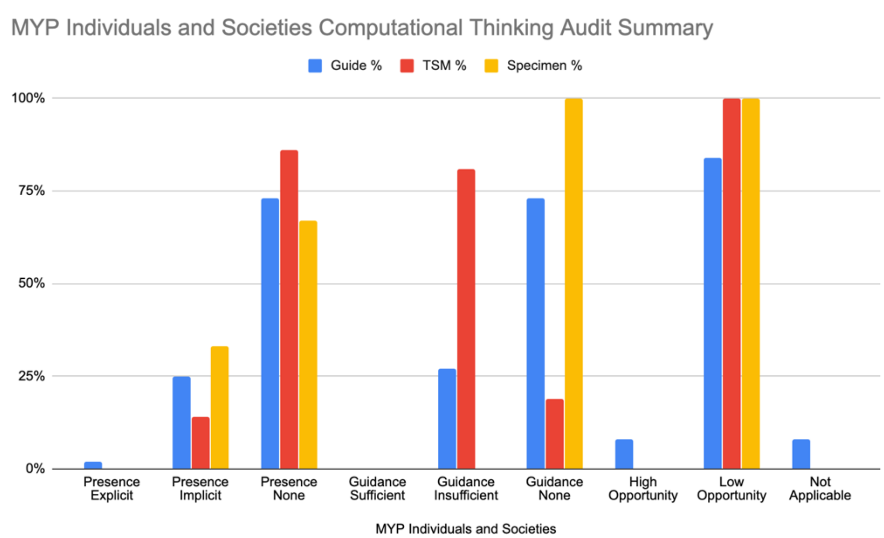


Figure 37. Coding of Design Thinking for MYP Individuals and Society Documents

Specific PYP Scope and Sequence Guides

1. PYP Learning and Teaching

The notions of a PYP learner, including agency and self-efficacy within a community of learners, are consistent with autonomous inquiry, design and the use of computation to address problems. Thus, it is clear that DT and CT could be well aligned with the PY programme. Transdisciplinary themes are a strength, inviting connections to the real world, as well as collaboration and creativity (e.g., “Sharing the planet”, "How the world works", “Where we are in place and time” and “How we express ourselves”). The open-ended nature of the programme of inquiry, and the fact that it bridges the early and primary years, allows schools to create a community of learners in which design thinking could be fostered. One consideration would be to be explicate the connections to CT and DT within these guides, weaving in guidance about how to support these forms of inquiry and cognition. Discussions of the learner profile or transdisciplinary learner, for example, could be well suited for the inclusion of DT and CT as important competencies.

The guide is explicit in its emphasis of collaboration and creativity, for example: "Collaboration enables lateral, imaginative and creative thinking about solutions to problems" (p. 16). Finding solutions through action is another principle that is quite consistent with design thinking as well as computational thinking. The focus on concepts and conceptual understanding would also lend itself nicely to design oriented activities (inquiries).

The notion of multiple interacting literacies—including technology literacy—is very appropriate for the Primary Years Programme and offers a good way for teachers to keep CT in mind. To support the development of CT, these guides offer some very good quality summary statements (e.g., "Supporting young learners’ development of computational thinking skills begins with algorithmic thinking —the ability to follow a series of ordered steps to solve a problem. For early learners, teachers and parents might consider introducing students to algorithmic thinking using tangible objects, which students could manipulate by following symbols or sounds or basic coding principles (Futschek and Moschitz 2011). For primary years learners with a slightly more developed algorithmic skill, the learning community might consider suitable programming environments such as Logo, Alice, Scratch, and so on. By applying computational thinking, learners “become not merely tool users but tool builders” (Barr and Stephenson 2011). They also innovate as they use critical and creative thinking skills to combine, adapt to and develop new technologies, as needed, to identify solutions and to create real and virtual artifacts." -- p. 55 of the learning environment document), as well as some examples. A very similar approach is taken for DT, where there is a short section in the Learning Environment section, pages 55-57. The guidance may not be quite sufficient here, to get PYP teachers or programme coordinators over the hump of actually understanding and integrating CT and DT

Opportunities and Considerations

The guide offers a deep treatment of the transdisciplinary nature, and how to craft a programme of inquiry, which would offer opportunities to integrate DT and CT. The action orientation of the inquiries, and particularly the Exhibition, seem like excellent opportunities to integrate design and computational elements. The focus on teaching practices in the guide, particularly around the approaches to developing inquiries, would offer a very good place to insert some treatment of DT and CT. The Approaches to Learning section is one pace there is clearly a good chance to introduce treatment and guidance of DT and CT. The "responsible, student directed" aspect of inquiry (e.g.,. p. 41) seem highly consistent with DT and would also lend themselves to DT, with a bit more explicit connection and guidance. The teacher's role in inquiry, and related sections of the guide are done already in such extensive detail, they provide an excellent place where more connections and guidance could be added (e.g., pages 42-44 of guide). One place where there is a strong connection to CT is in the Technology section of the Learning Community document (pages 48-61). A strong statement is made that, "Technology plays a key role in an inquiry-based programme that aims to support the development of international-mindedness and attributes of the learner profile. Schools offering the PYP create opportunities for students to develop explicit knowledge and skills relating to technology, apply technology to facilitate and extend learning, and adapt it in new ways to create solutions to challenges and opportunities." (p. 51), and even a section explicitly addressing Computational Thinking, (p. 54).

In general, there was not much treatment of computation, although there are some references to patterns and algorithms and modeling in the conceptual sections (e.g., p. 53-54). Technology and information literacy is introduced as an important dimension of young learners' development, and there is a companion document for technology integration (coded separately) - so the guidance may be sufficient there. But the role of computational thinking could certainly be added to these high-level documents, supporting more direct references and applications within the other topics (math, science, technology).

Information skills and media literacy skills are very nicely explicated and unpacked for teachers, with guidance on how to integrate them within student inquiries. This would be a good way to include CT and DT as well. In the Inquiry section of the guide, there are many implicit references to testing theories and experimenting that would be consistent with CT (e.g., "making predictions and acting purposefully to see what happens; collecting data and reporting findings; researching and seeking information; establishing and testing theories" (p. 41)- while these do not explicitly recognize CT, they would be a very suitable place to introduce such language. The "developing a programme of inquiry" section would also be a great place to add guidance for how teachers could integrate design and computational thinking. Presumably, the Assessment section of the guide (p. 67-81), which is superb, would also want to add some explicit treatment of CT and DT, as "ways of thinking" that would be assessed according to the PYP model.

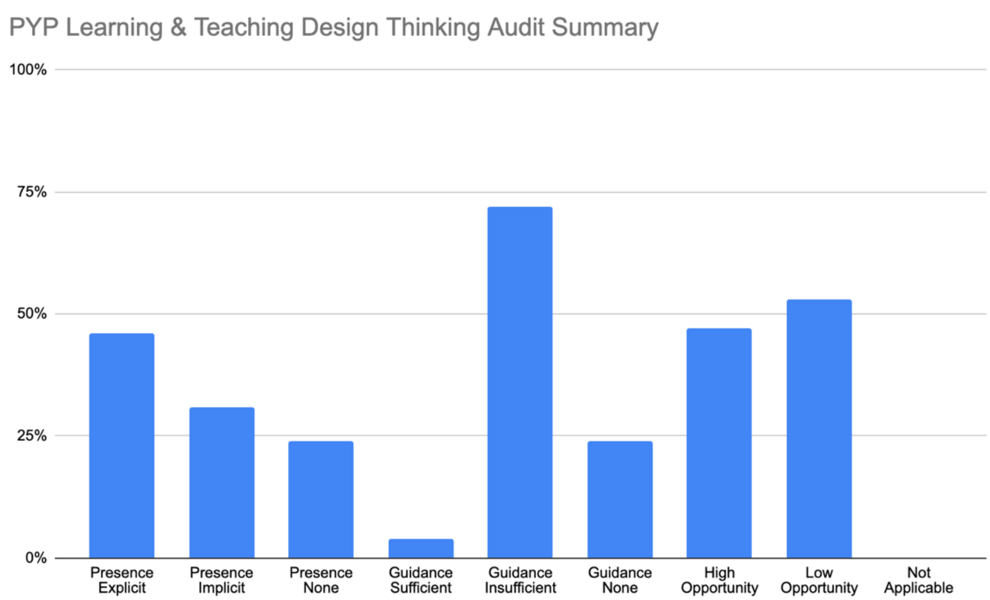


Figure 38. Coding of Design Thinking for PYP Learning and Teaching Documents

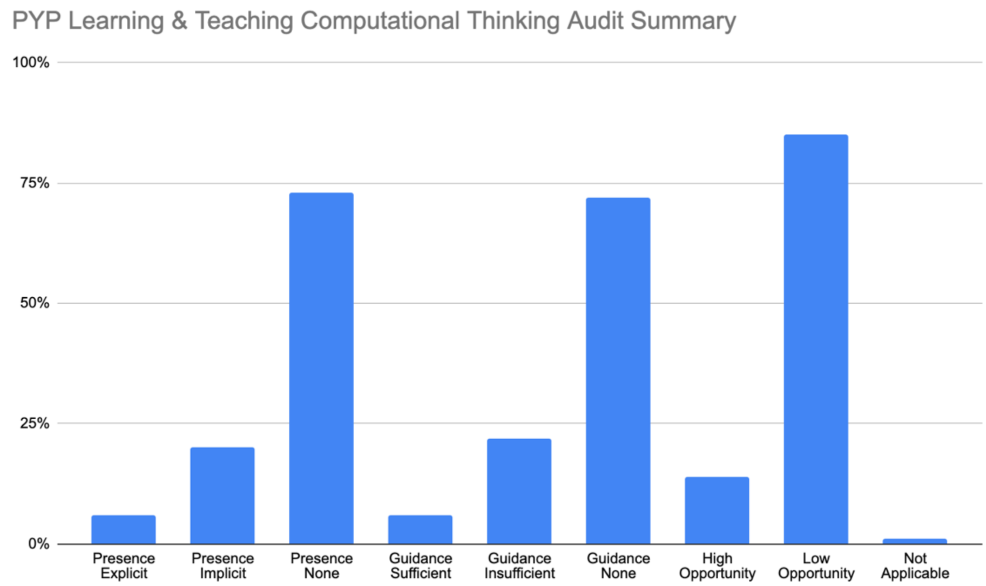


Figure 39. Coding of Computational Thinking for PYP Learning and Teaching Documents

2. PYP Math

The PYP Mathematics Scope and Sequence (S&S) has a strong emphasis on learning mathematics in the context of solving real-world problems throughout the entire document. Collaboration is also salient theme in the sections on mathematical practices and the key concepts section. In particular, perspectives from different individuals and groups are described as an important aspect of practicing math. Additionally, math concepts such as measurements, standard units, and mathematical terminology are characterized as "common language" for describing the world we live in.

Pattern recognition, abstraction, and algorithms are strong themes in the S&S. This is not surprising as computing partially builds on mathematics, therefore share many ways of thinking with mathematics. The S&S characterizes mathematics as a language, a way of thinking, an effective tool to explore the world through its unique perceptions. These characterizations are in line with how we define CT.

Although the S&S emphasizes real-world contexts, it is unclear how open-ended the problems should be. There are a few links to the creativity dimension. In the sections on mathematics practices, learners are encouraged to create their own symbolic notation and problem-solving strategies to develop conceptual understanding before transitioning to conventional notations and strategies. However, the creative process described here only serves as a scaffold for formal learning. There is little link to the "evaluations accurately assess DT" dimension.

There is only one link to decomposition in the Key Concepts in the PYP section, in which "systems", "components", and "levels of relationships" are mentioned. Decomposition is a necessary strategy for solving complex problems. The links to algorithms are relatively implicit, often reflected in the practices of justifying one's solutions and using technologies. There is very limited link to these the Testing & Debugging and Iteration dimensions.

Opportunities and Considerations

S&S developers may consider providing more examples of open-ended problems and how teachers should guide students to define the problem, reduce the complexity, and build and test math models — essentially the practice of math modeling. Building on the characterization of mathematical terminology as "common language", the S&S may further elaborate on how mathematics serves as the foundation for complex collaborative efforts. A potential link to the creativity dimension is in the Data handling section. Activities such as "design a survey" and "create and manipulate an electronic database for their own purposes" have great potential to engage students in creative thinking. Consider suggesting more activities that require creative thinking in the Learning Continuums sections, especially under the "Applying with Understanding" stages. To link to the evaluation dimension, consider adding DT criteria in these sections: "How mathematics practices are changing", "knowledge and skills in mathematics", "key concepts in the PYP", and "Learning Continuums"

To better link to the algorithms dimension, the S&S could suggest activities that require students to develop instructions for peers or computers to carry out the solution steps. The S&S could also suggest that teachers elevate the complexity of the problems presented to students so that they have the opportunity to practice decomposition. For example, in the Data handling section, consider suggesting handling complex data involves creating multiple and possibly linked spreadsheets. To link to the Iteration and Testing & Debugging dimensions, the S&S could include math modeling as a central practice and then highlight the model testing and the iterative nature

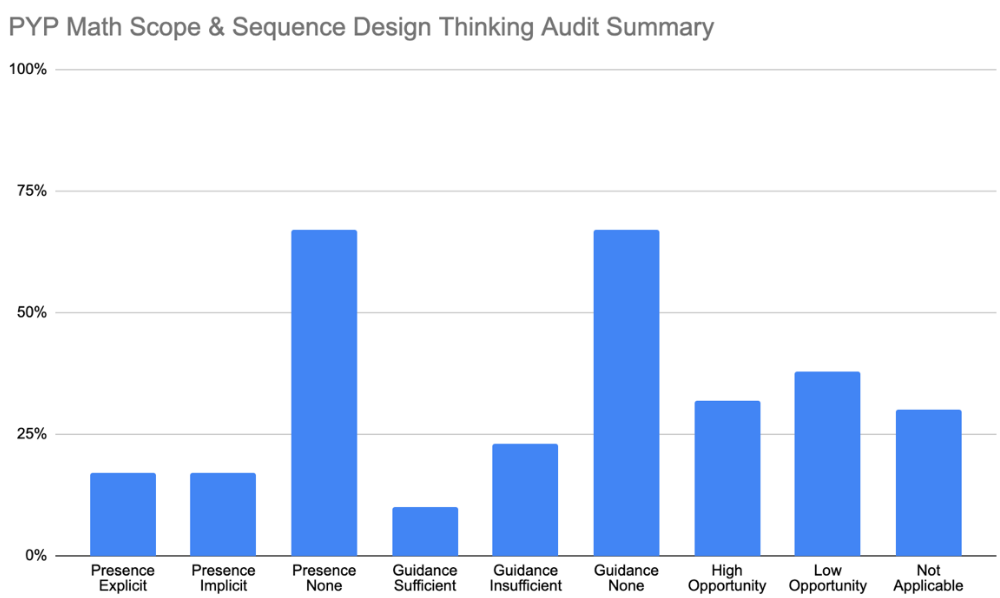


Figure 40. Coding of Design Thinking for PYP Mathematics Documents

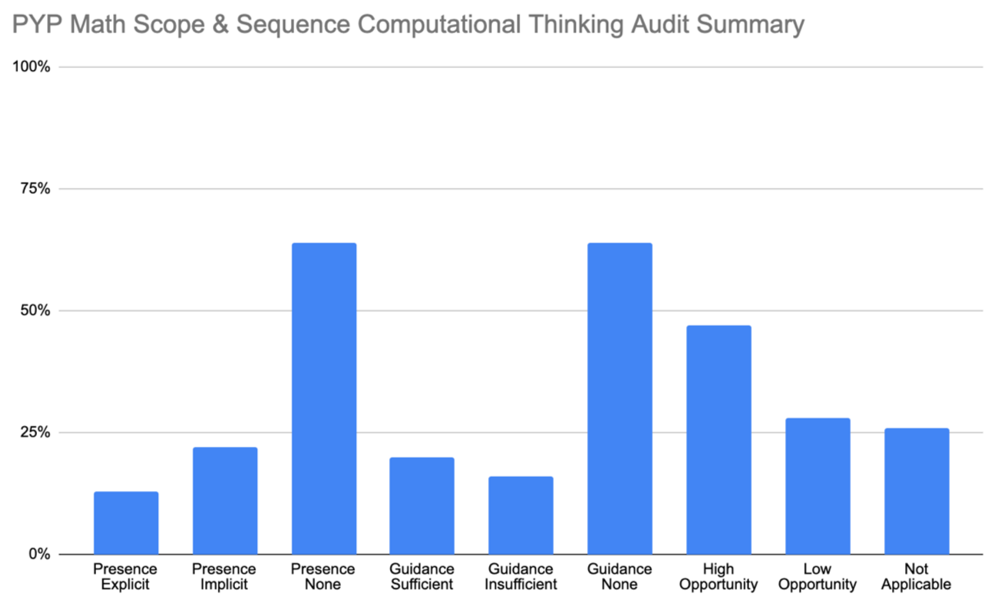


Figure 41. Coding of Computational Thinking for PYP Mathematics Documents

3. PYP Science

There is a general emphasis, in the opening section, on the importance of science within transdisciplinary inquiry projects, emphasizing relevant topics, and autonomous student inquiry (e.g., "challenging students to answer open-ended questions with investigations so that they can abandon/modify their misconceptions by observations, measurements or experimentation:" --p. 3). There are some implicit references to elements of DT (e.g., real world problems, collaboration), but mostly these are left quite thin and with very little guidance. For all age levels, there are some references to some relevant DT and CT subskills, such as (1) the ability to identify or generate a question or problem to be explored, (2) making and testing predictions, and (3) carrying out systematic investigations. So, these are implicit elements of DT and CT, but never connected explicitly, nor receiving any guidance for teachers. Considerable level of attention is given to the nature of science, and the challenges of creating student inquiries are clearly left as a matter for the other Learning and Teaching guides, etc. This seems appropriate but does not leave much room for building explicit connections to CT and DT within the sciences guide. As in the higher level (MYP and DP) science courses, there is more emphasis placed on systematic investigation and experimentation, than on exploration and iterative improvement. DT and CT are never recognized explicitly as being connected to science inquiry, although again, the Learning and Teaching guides make those connections quite explicit including some guidance.

Computational Thinking was largely absent from this Scope and Sequence guide, with the exception of some specific skills relating to interpreting and gathering data, and considering models. But these are largely incidental connections, with no explicit reference to CT. Indeed, technology and computation do not appear in this document, and that is an area where there could likely be some improvements. What is the role of scientific simulations for different age groups? These are technologies that are widely used by science teachers in primary and middle years, so it could be advisable to offer some treatment in the Scope and Sequences guide. The same would be true for both DT and CT.

Opportunities and Considerations

As noted above, in the review of the Learning and Teaching guides, an emphasis on causal understandings will help support the use of design-oriented projects in the inquiries and exhibitions. It could potentially strengthen the Science S&S guide to include some cross connections to those other guides, including the CT and DT sections of the PYP Learning Environment document., and likely the technology integration document as well. Mainly, the Scope and Sequence guide consists of tables of expectations, including both (1) Knowledge, concepts and skills, and (2) possible learning outcomes. But no examples are provided (i.e., of student inquiries or exhibition ideas), nor any explicit guidance for how to make connections to CT and DT. Given that these elements have been recognized as having a high priority at the programme level, it is worth considering the inclusion of some guidance to support those connections, or at least to place reminders that science is one place where they could be supported. Some examples for science (as well as math, social studies and technology integration) would also be useful.

Certainly, for the older years (7-9, and 9-12), there should be opportunities to engage in design projects (e.g., for exhibitions). In the transdisciplinary theme of "How the World Works", for example, one line of inquiry given for ages 9-12 was Renewable and sustainable energy. This topic is very well suited to a design project.

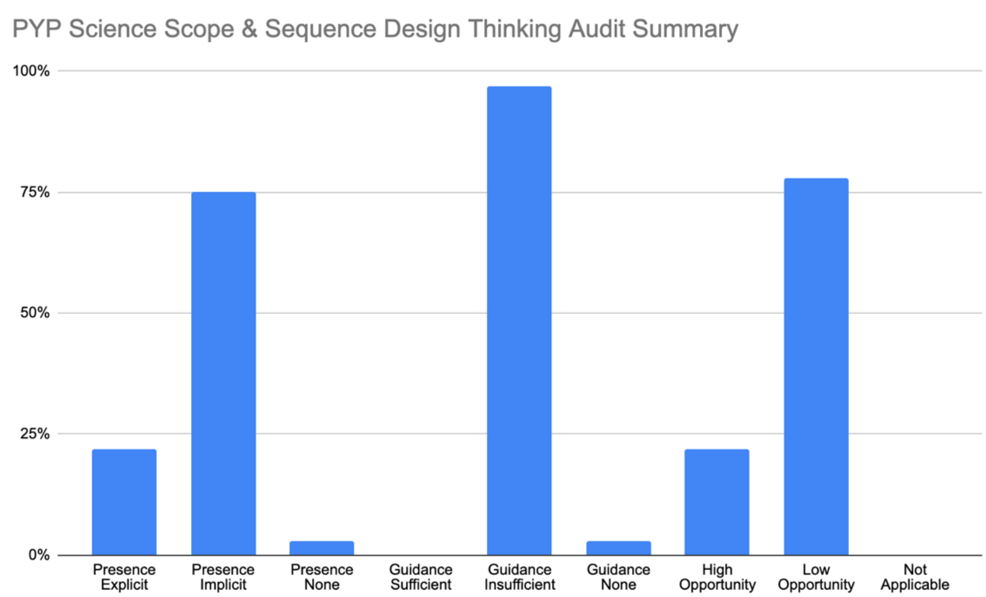


Figure 42. Coding of Design Thinking for PYP Science Documents

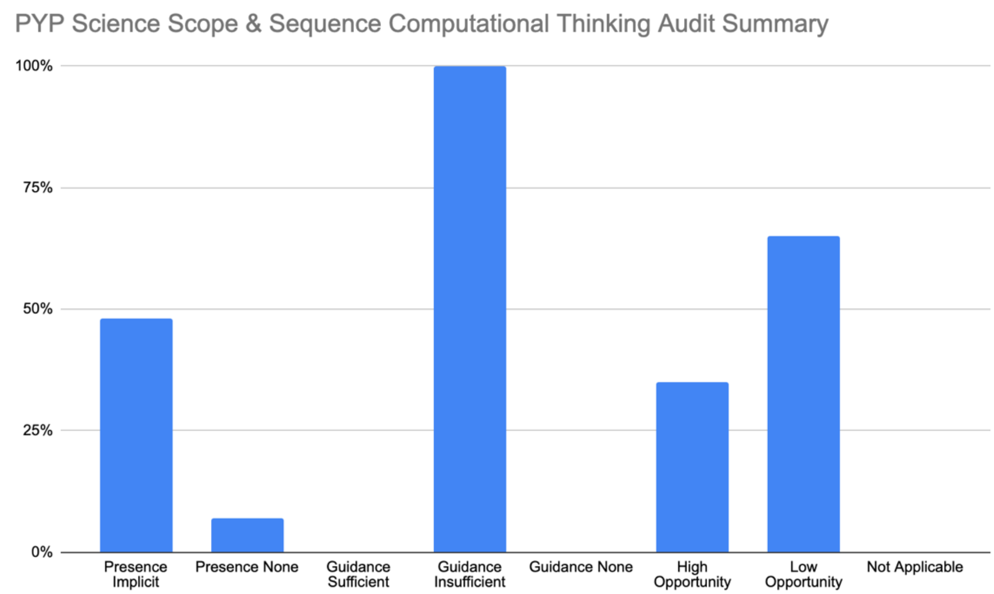


Figure 43. Coding of Computational Thinking for PYP Science Documents

4. PYP Social Studies

Where present in the guide (see year 5-7), the opportunities to engage in DT are quite strong and offer students a lot of room to think creatively. Most of the tasks and activities are situated in real-world situations. In some cases (not all) students are also given some freedom in how they go about addressing and designing solutions for these activities.

While there are not a lot of clear connections to CT in this course, there were several instances where Decomposition and Pattern Recognition could be applied. For instance, the similarities between cultures or buildings etc. are nice examples of possible Pattern Recognition

The opportunities to engage in DT are not consistent across the years and are especially absent in 9-12. While the problems are situated in real-world situations, in many cases, it is not clear whether or not the students are actually given the opportunity to design anything. THis becomes increasingly the case as the programme progresses, with the 7-9 and 9-12 seeming to lack a clear problem to address. There also seems to be a distinct lack of collaboration in the guide. Overall, the nature of the course makes connections to DT less common than in other subjects.

Opportunities and Considerations

The two key opportunities that stand out in this course are: a) finding spots where students can connect with real problems (many of the items in the curriculum lack a problem for students to solve) or design opportunities. The early years have some of this with the tasks like coming up with class rules and routines (Y3-5) and identifying a problem to be explored in relation to human impact on the environment (Y5-7), but it tapers off in subsequent years. While collaboration is not mentioned in years

5-7 and 7-9, students could gain a lot of depth to their work and understanding of the tasks through collaboration. This seems like a clear double win.

Where students are tasked with working on analyzing data, teachers could use these activities as a means for effectively integrating CT. This will take some work to specify this clearly enough in the guide, both in terms of the tasks that students will engage in and how they connect to CT.

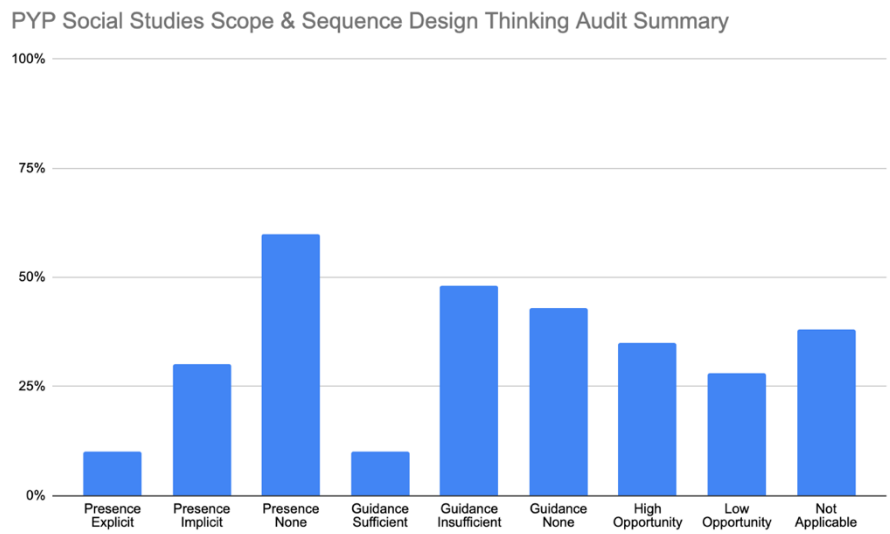


Figure 44. Coding of Design Thinking for PYP Social Studies Documents

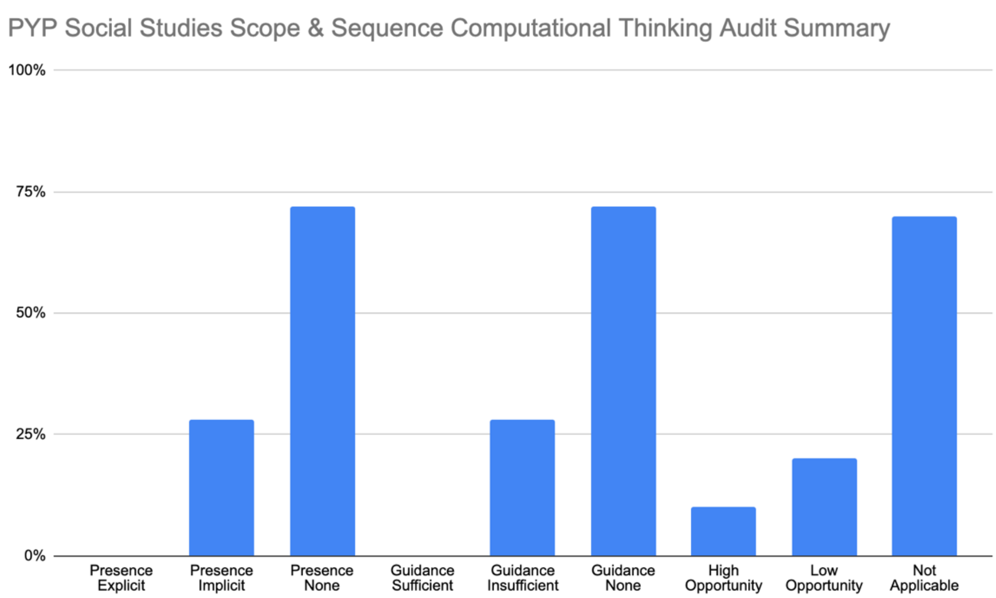


Figure 45. Coding of Computational Thinking for PYP Social Studies Documents

5. PYP Technology Integration

"Purposeful Technology Integration" is a high quality document, but does not yet seem to be in its final form (e.g., a typo in the first page: "this teacher support material, Eleni Kyritsis of explores") - and could be strengthened by a paragraph of introduction that explains why technology integration is important, how it connects to the IB vision, and the PYP models, before proceeding to the case study. But the case study itself is quite useful as a teacher support material, giving very pointed illustrations, that have clear implications and applications to a wide range of potential PYP inquiries. The main usable part of this TSM is the "Bringing technology to Life" section, which includes some rich examples, as well as a few qualitative statements that offer guidance to teachers (although these were quite limited, and did not really offer design principles or best practices). There was also a section explicitly dedicated to the support of "Design Thinking".

There is an explicit connection made to computational thinking, with regard to children's learning to code: "Coding underpins thinking, communication and self-management skills. With trial and error comes resilience and a problem-solving approach." (p. 7). Again, these are very short sections providing not much more than a taste, or sense of direction. But they are certainly pointing in the right direction. The main way to improve would be to provide more details about the various inquiry designs, and more explicit commentary and guidance for teachers.

Computational Thinking was largely absent from this Scope and Sequence guide, with the exception of some specific skills relating to interpreting and gathering data, and considering models. But these are largely incidental connections, with no explicit reference to CT. Indeed, technology and computation do not appear in this document, and that is an area where there could likely be some improvements. What is the role of scientific simulations for different age groups? These are technologies that are widely used by science teachers in primary and middle years, so it could be advisable to offer some treatment in the Scope and Sequences guide. The same would be true for both DT and CT.

Opportunities and Considerations

Many opportunities for improving the integration of DT could be found in simply adding more discussion and guidance to these examples. Even better would be to provide a lengthier treatment of the examples. The example to support Design Thinking (p. 4), leads with an overview: "Technology supported the students' research skills as they investigated different forms of energy, including renewable energy.". The section only presented 4 sentences about this lesson, totaling 140 words. These words were quite well written, culminating in "This process helped one group explore a theory about the potential of converting the enzymes in chocolate into a form of electricity by melting—really creative thinking!"... But this summary comes up short of providing real guidance to helping teachers develop their own inquiries or try to use this one. Some more detail, including examples of student work, and specific connections to design thinking would surely make this example more useful. In the Questions section, the authors might also consider adding specific questions regarding DT and CT.

There is an explicit connection made to computational thinking, with regard to children's learning to code: "Coding underpins thinking, communication and self-management skills. With trial and error comes resilience and a problem-solving approach." (p. 7). Some reference is made to Bee Bots as a means of engaging young students' CT, but... no details, nor examples of student work. In its present form, this case study approach is a very good "pointer in the right direction". In the Questions section, there are none that are relevant to the integration of CT, and the Next Steps section is quite thin, simply pointing back to the technology section of the Teaching and Learning documents.

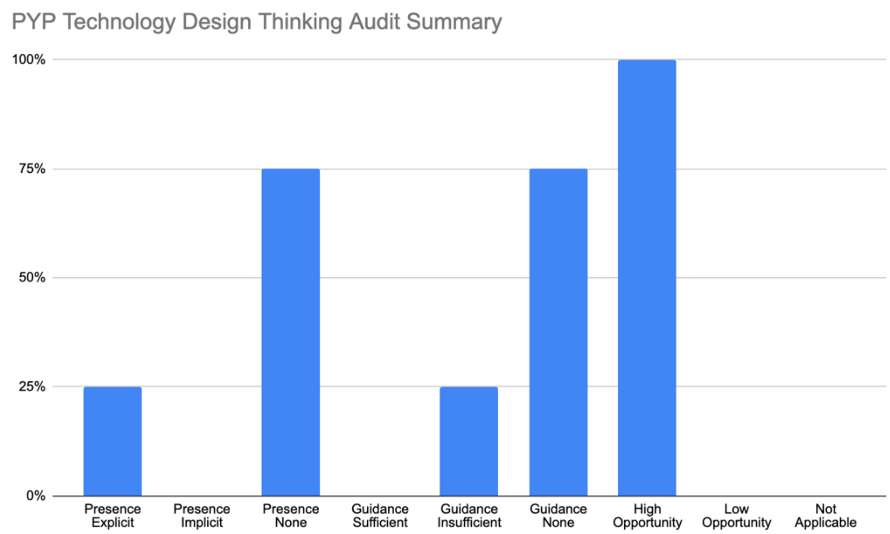


Figure 46. Coding of Design Thinking for PYP Technology Integration Guide

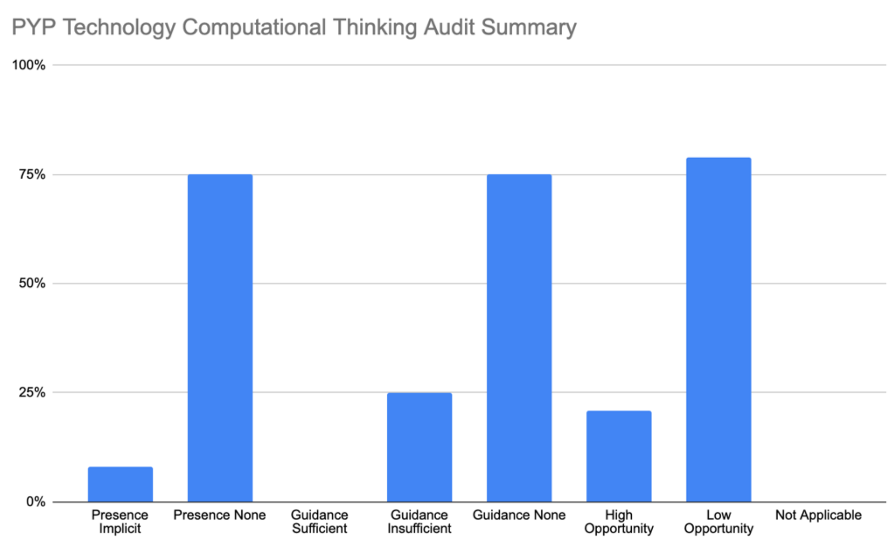


Figure 47. Coding of Computational Thinking for PYP technology Integration Documents

Fostering Computational Thinking and Design Thinking in the IB PYP, MYP and DP

Appendix D

Supplemental Programme Coordinator & Teacher Survey Response Analysis

Appendix D. Supplemental Programme Coordinator & Teacher Response Survey Analysis

The Diploma Programme

We looked for interesting patterns in teachers' self-judgement about their understanding of DT and CT, comparing those with different levels of experience, from kinds of schools, and from different regions of the world, Figures 48 and 49 show that DP responses to the items described above (understanding of CT and DT) do not vary considerably across levels of teacher experience (0-3 years, 4- 10 years, more than 10 years, "programme coordinator"). Respondents were also quite consistent when compared across different school types (Charter, Private, State, and State subsidized) or Human Development Index (HDI -- low, medium and high countries) -- see Figures 50, 51, 52 and 53.

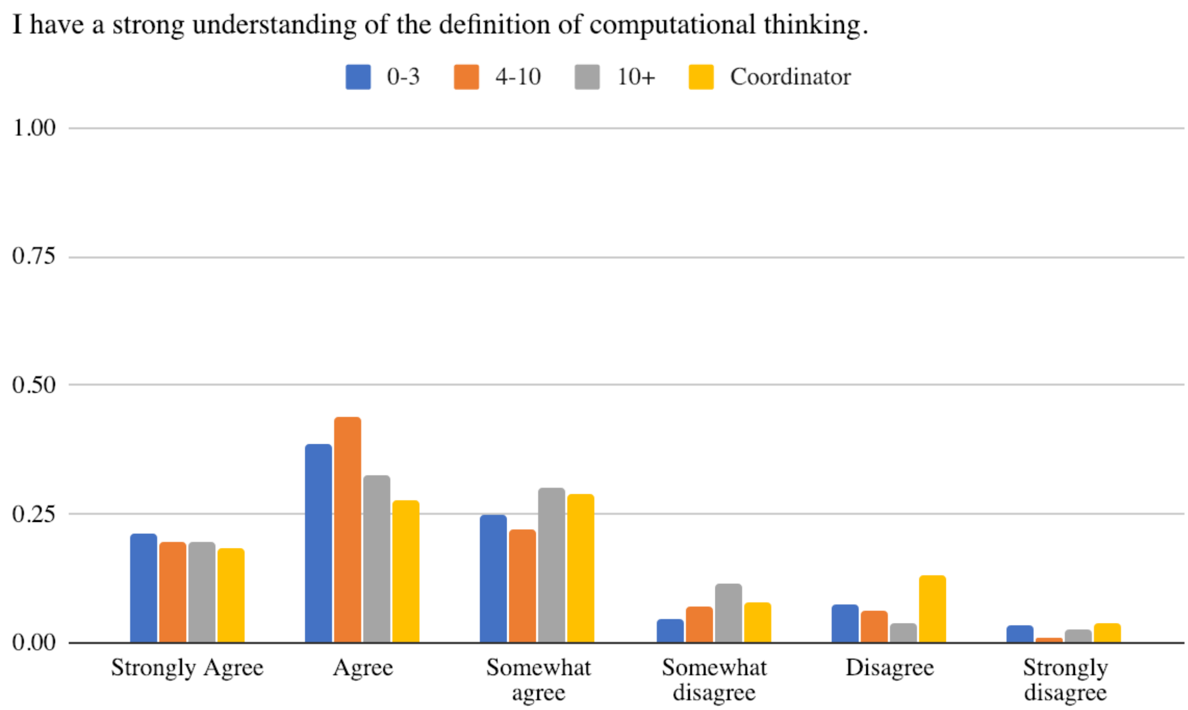


Figure 48. DP: Stated understanding of CT (split by experience level)

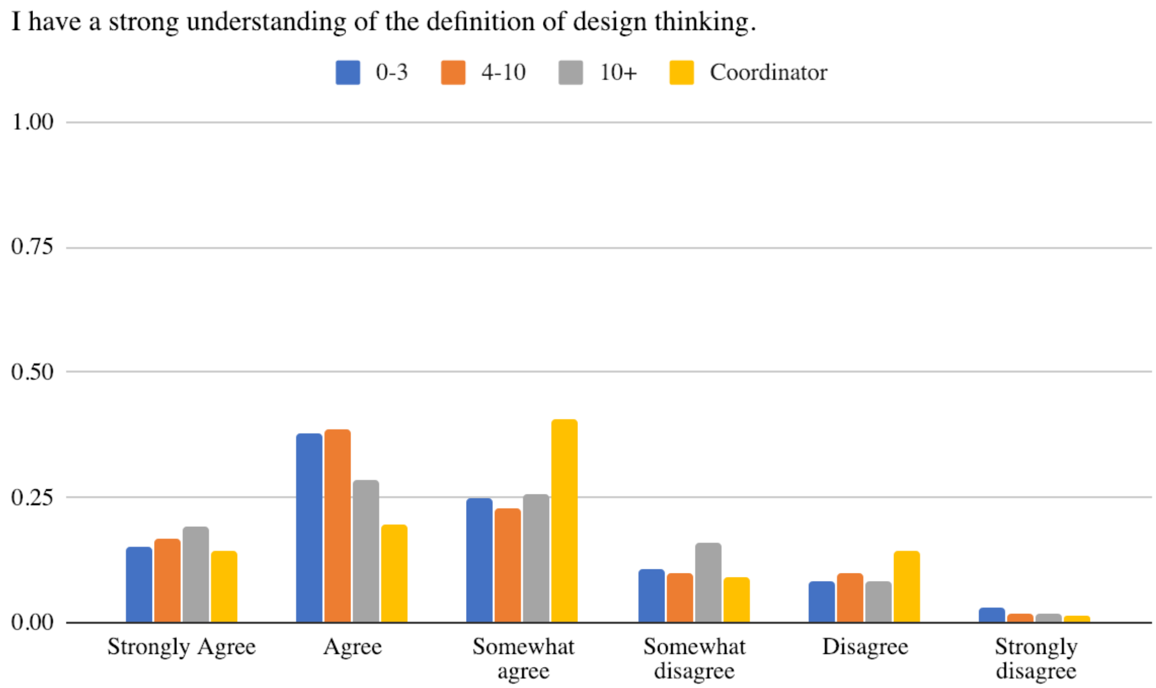


Figure 49. DP: Stated understanding of DT (split by experience level)

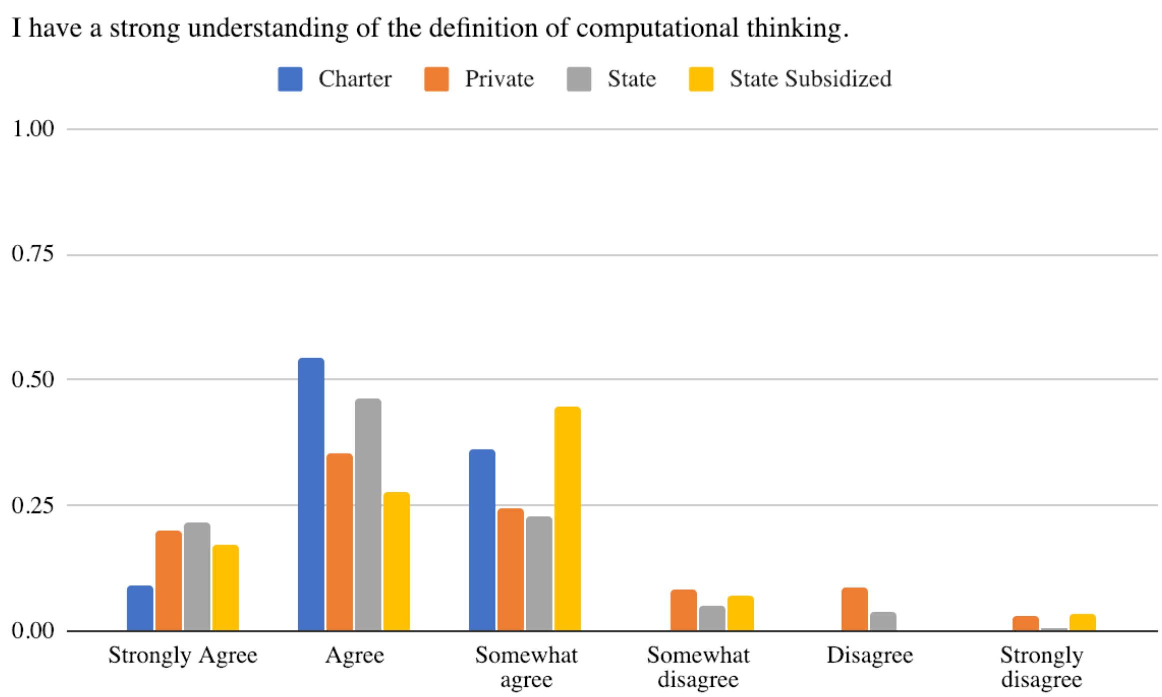


Figure 50. DP: Stated understanding of CT (split by school type)

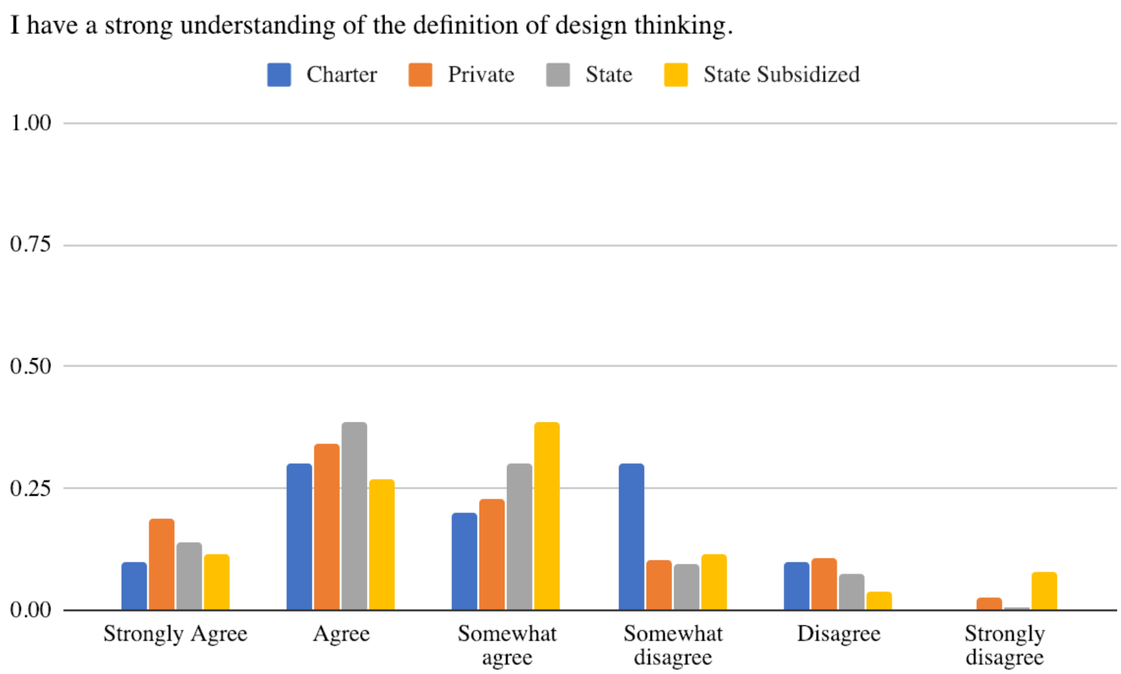


Figure 51. DP: Stated understanding of DT (split by school type)

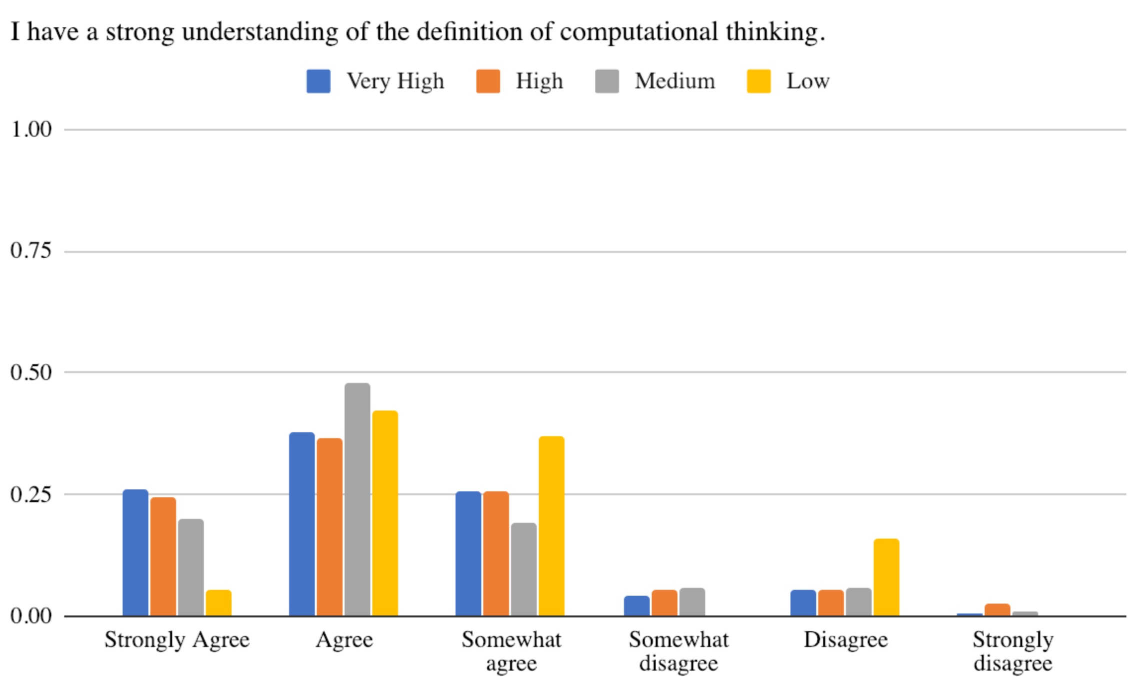


Figure 52. DP: Stated understanding of CT (split by Human Development Index)

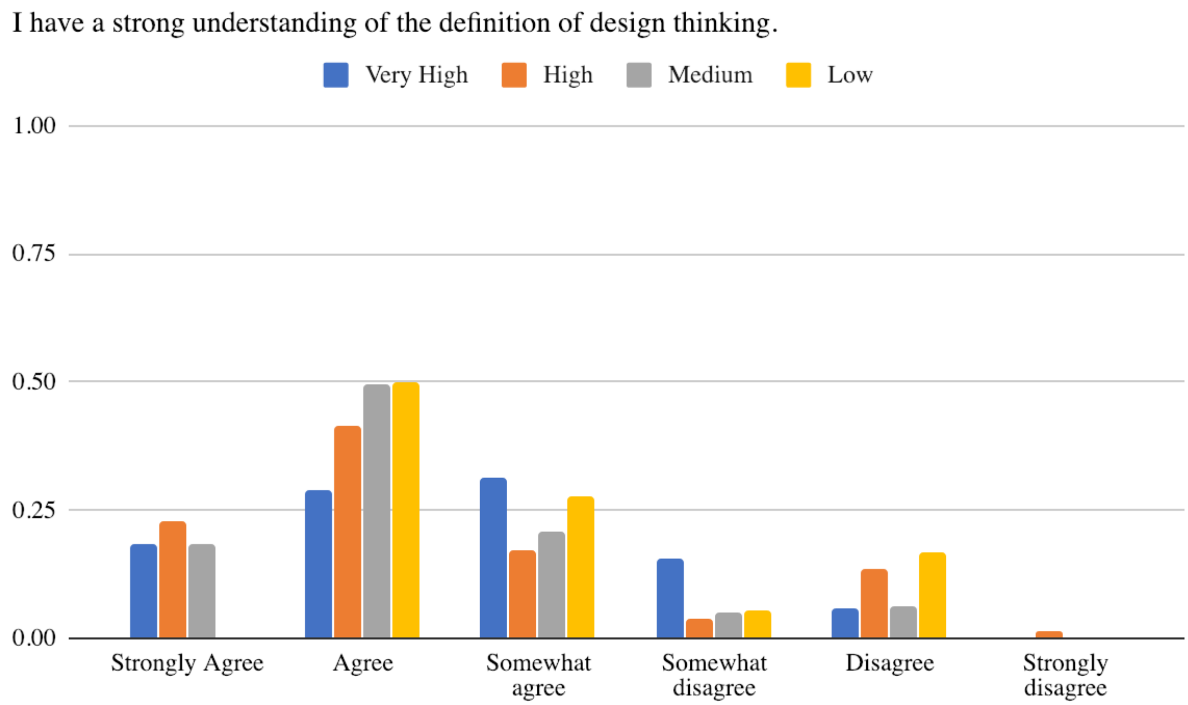


Figure 53. DP: Stated understanding of DT (split by Human Development Index)

The Middle Years Programme

As in our review of the DP survey responses, we again looked for differences amongst teachers from different levels of experience, kinds of schools, or regions of the world. With regard to teacher experience, Figures 54 and 55 show that MYP teachers' understanding of CT and DT is again quite consistent across the categories (0-3 years, 4- 10 years, more than 10 years, "programme coordinator"), although there are some interesting small differences within this broader pattern. When compared across different school types (Private, State, and State subsidized -- there were no respondents from charter schools in the PYP survey) there are some apparent differences (see Figures 56-57), with state subsidized showing much higher means for "strongly agree" - although this difference is probably due to the small number of respondents in that category (only 7 from state subsidized, vs. 50 from State and nearly 300 from private). When comparing respondents from different Human Development Index (HDI) categories, we see an apparent advantage in "strongly agree" responses from "high" and "very high" HDI countries, with "medium" countries responding a bit less favourably (see Figures 58-59). Overall, the patterns show a fairly consistent level of agreement or strong agreement by MYP respondents to the statement that they "have a strong understanding" of DT and CT.

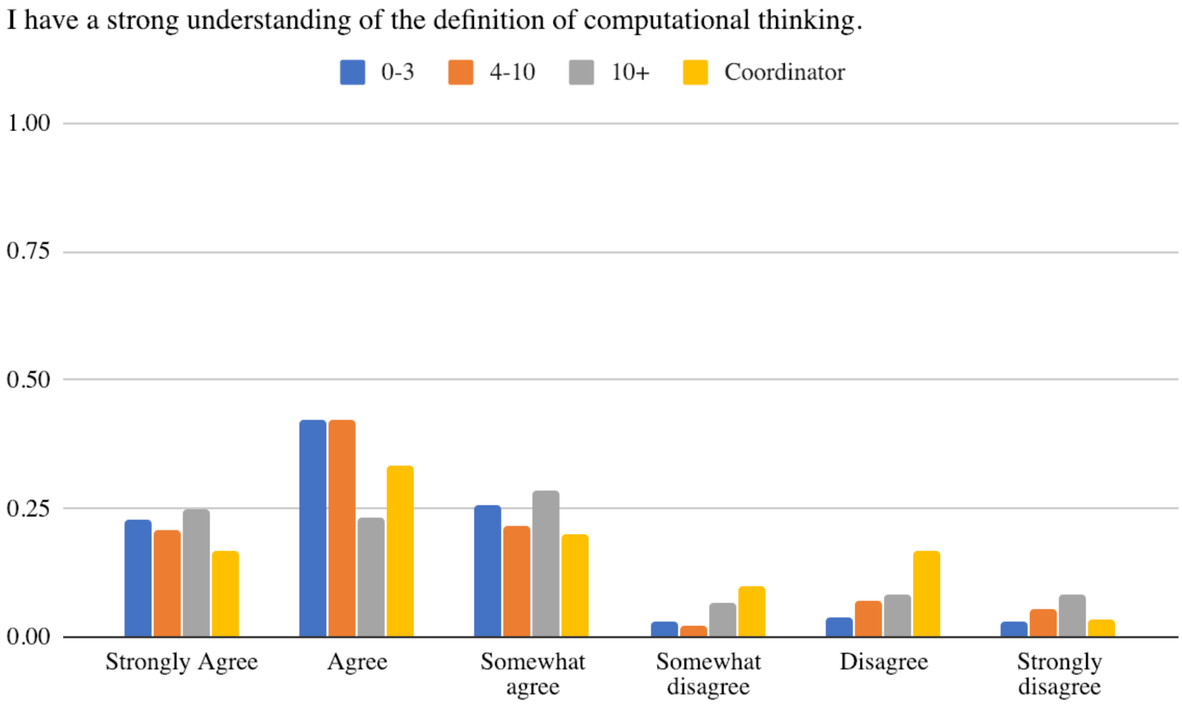


Figure 54. MYP: Stated understanding of CT (split by experience level)

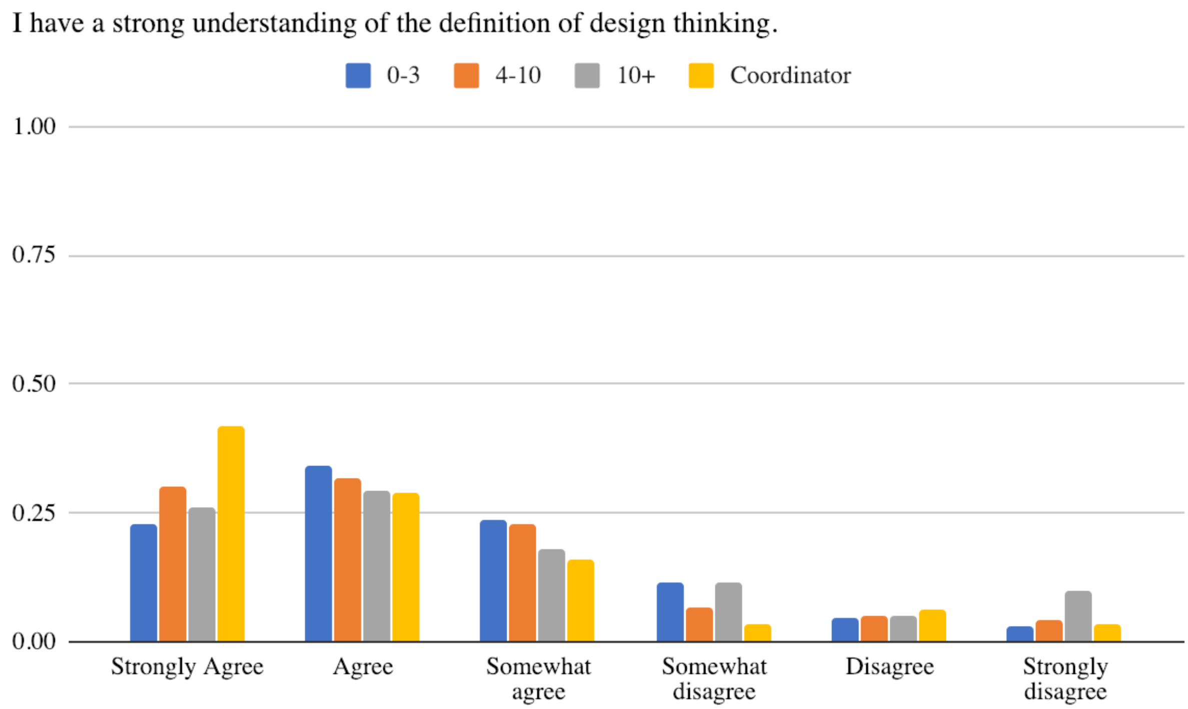


Figure 55. MYP: Stated understanding of DT (split by experience level)

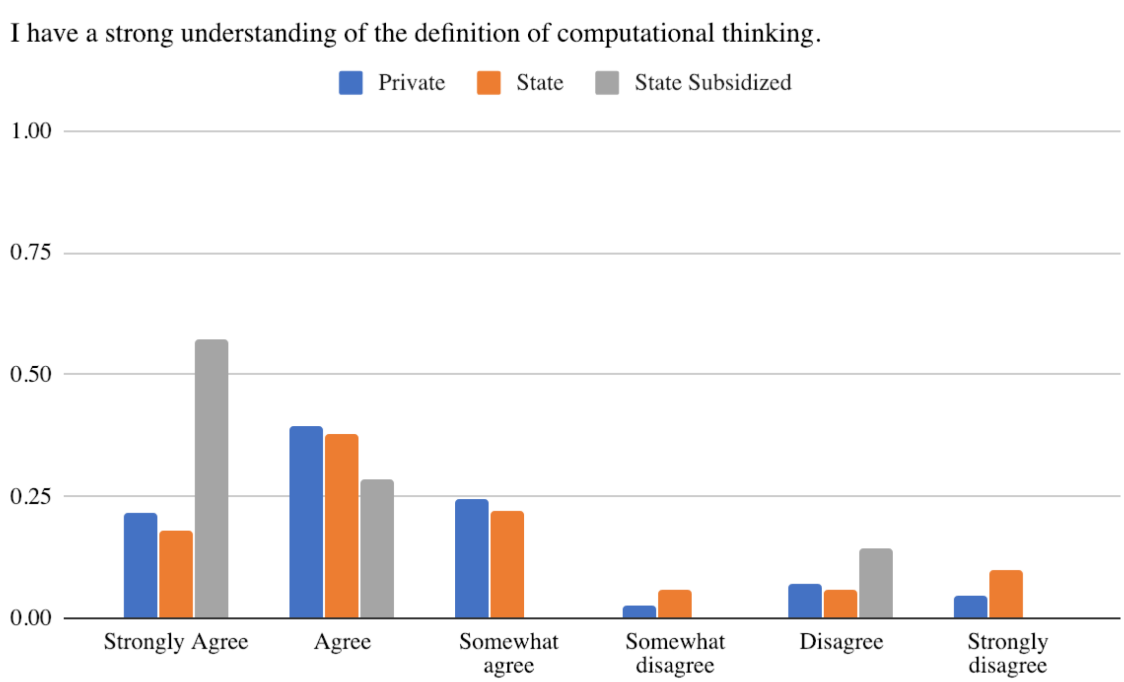


Figure 56. MYP: Stated understanding of CT (split by school type)

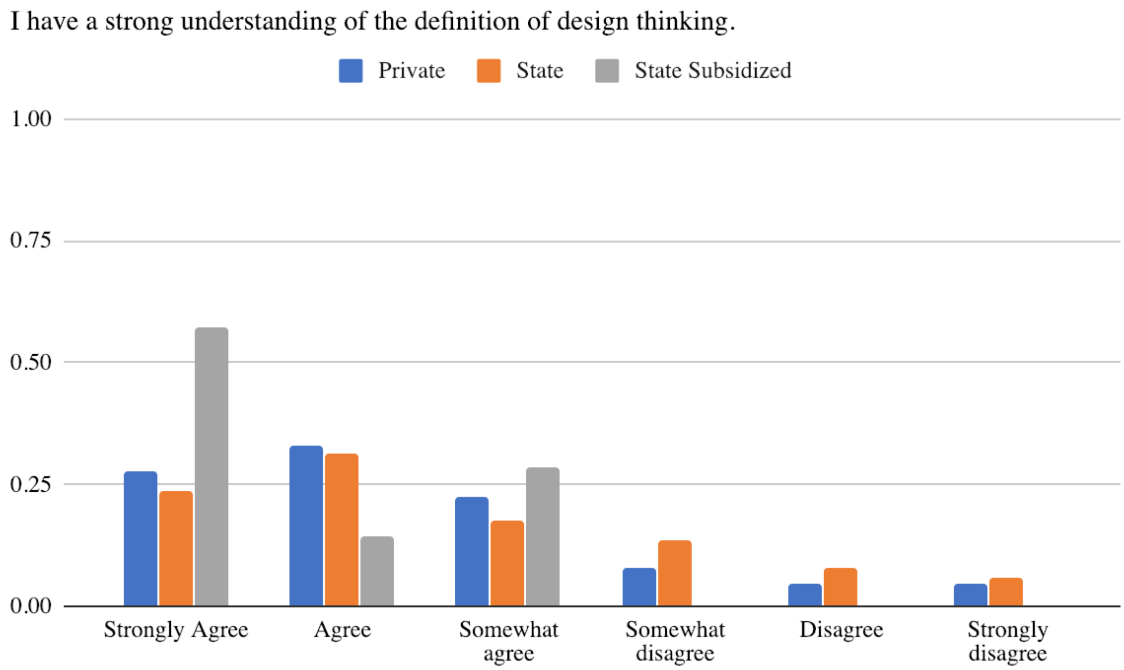


Figure 57. MYP: Stated understanding of DT (split by school type)

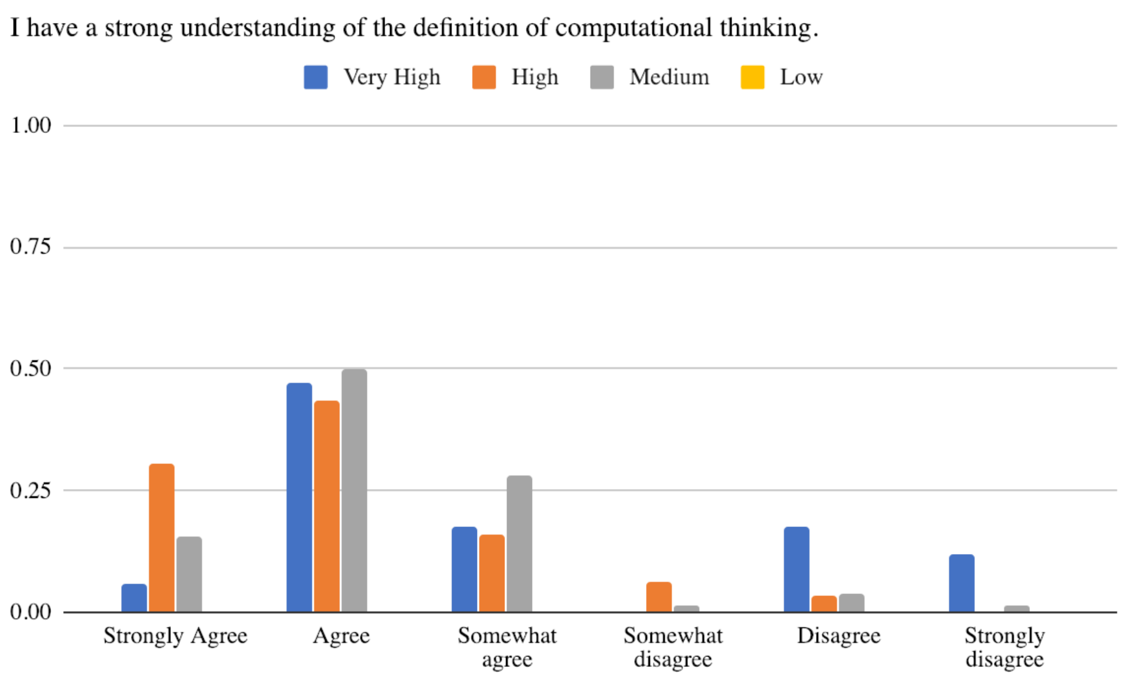


Figure 58. MYP: Stated understanding of CT (split by Human Development Index)

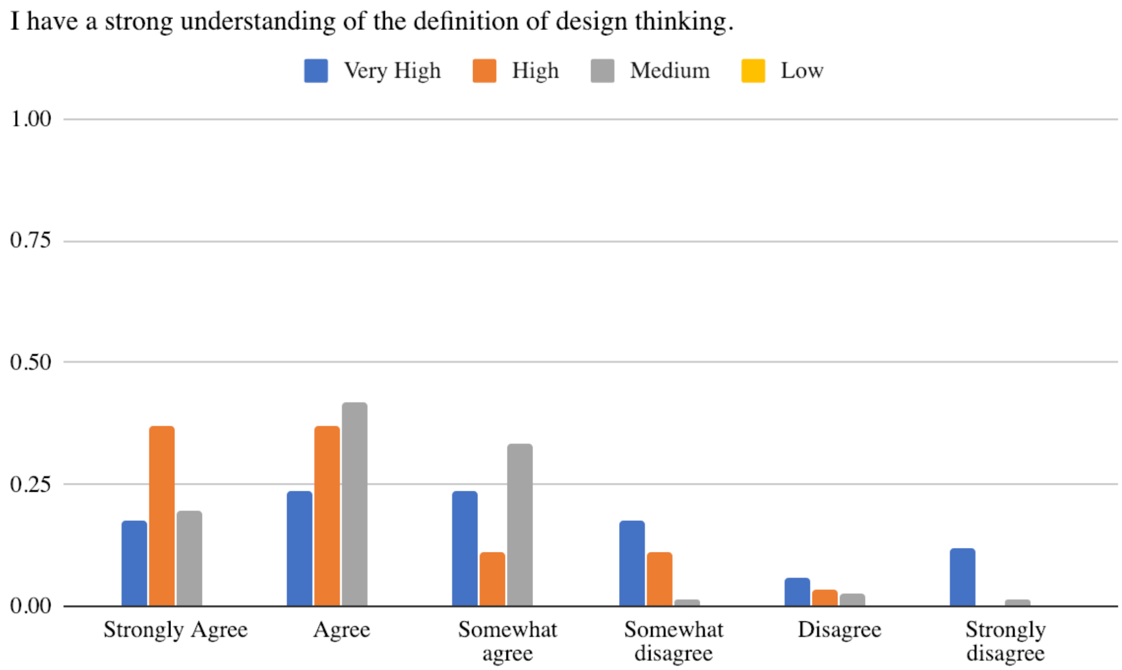


Figure 59. MYP: Stated understanding of DT (split by Human Development Index)

The Primary Years Programme

PYP teachers showed similar patterns as those of teachers in the MYP and DP, with some interesting features. First, the teachers with most experience (10 Years+) show much higher perceived understanding of DT/CT than their peers. But we suspect this is an artifact of the small numbers of PYP teachers in that category. Second, the charter school teachers seem to have a higher estimation of their understandings than those from state or private schools. Otherwise, we again see that teachers are fairly consistent in their responses, across any category scheme.

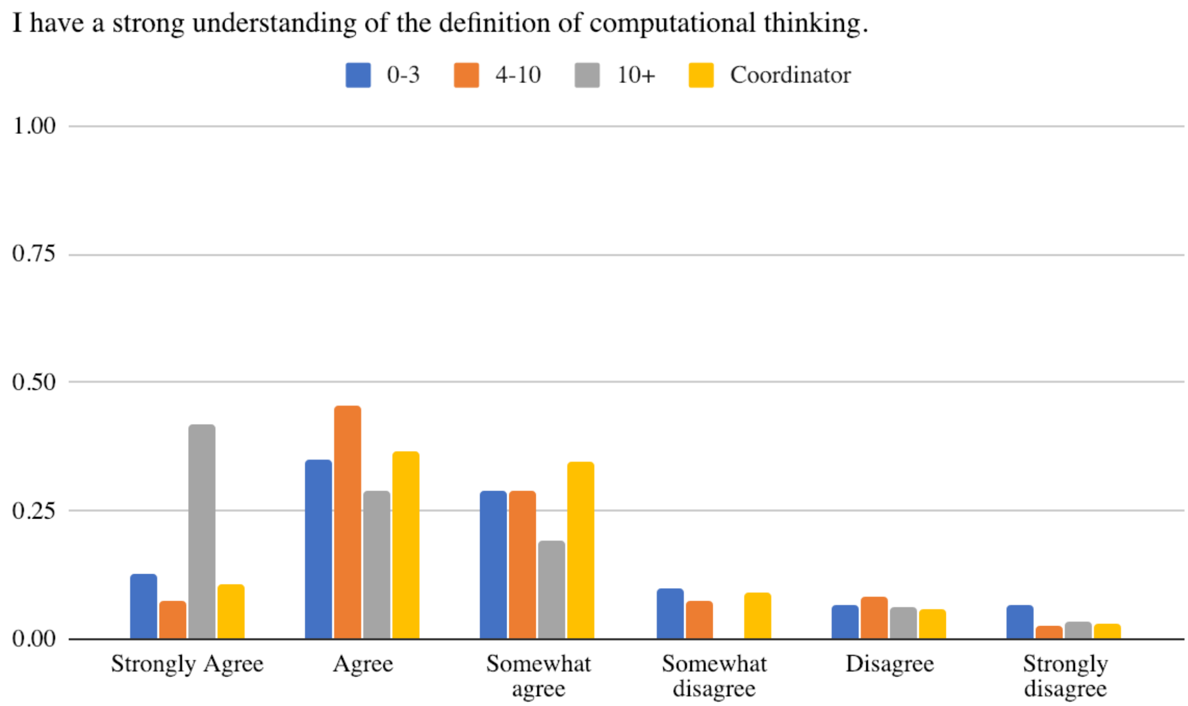


Figure 60. PYP: Stated understanding of DT (split by experience level)

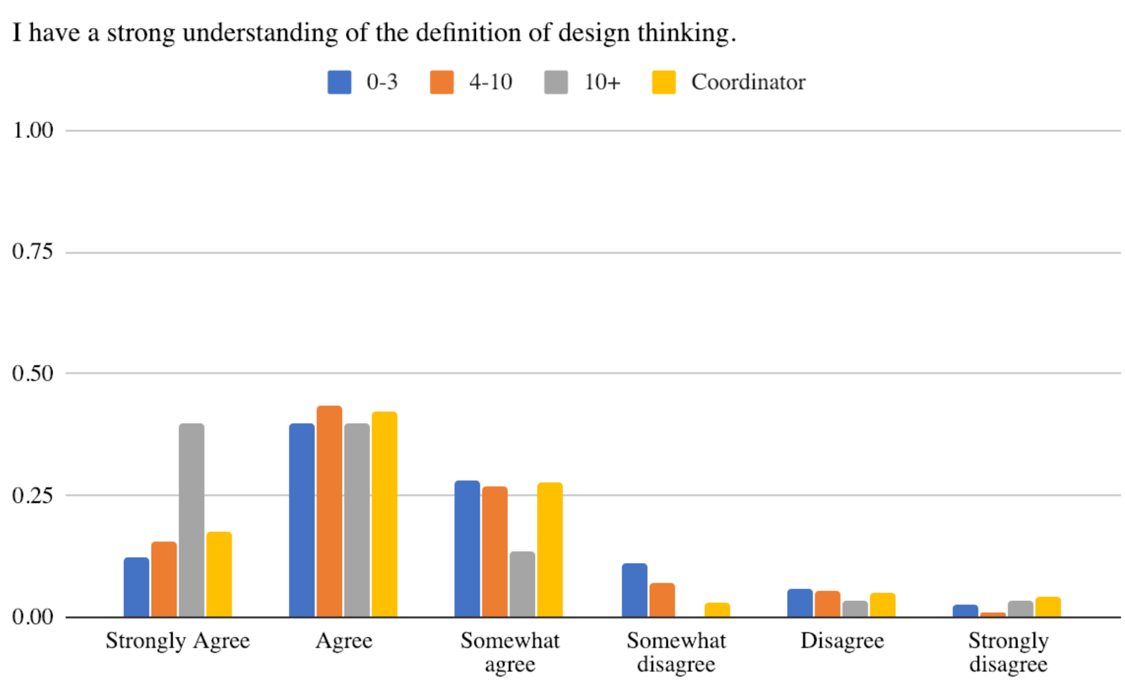


Figure 61. PYP: Stated understanding of CT (split by experience level)

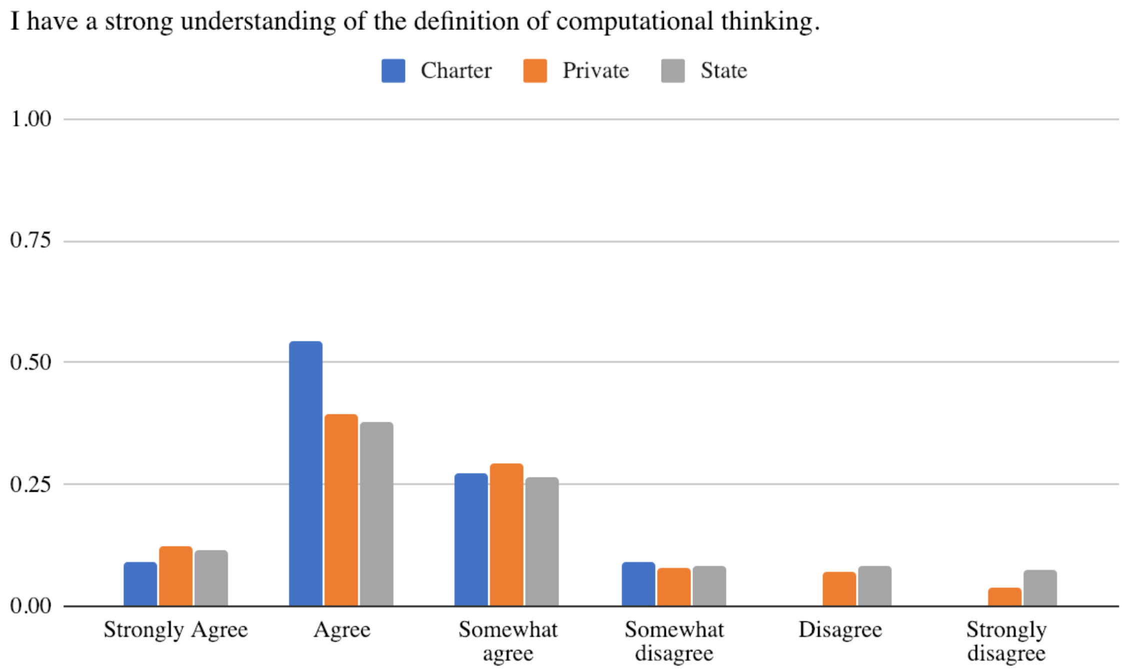


Figure 62. PYP: Stated understanding of CT (split by school type)

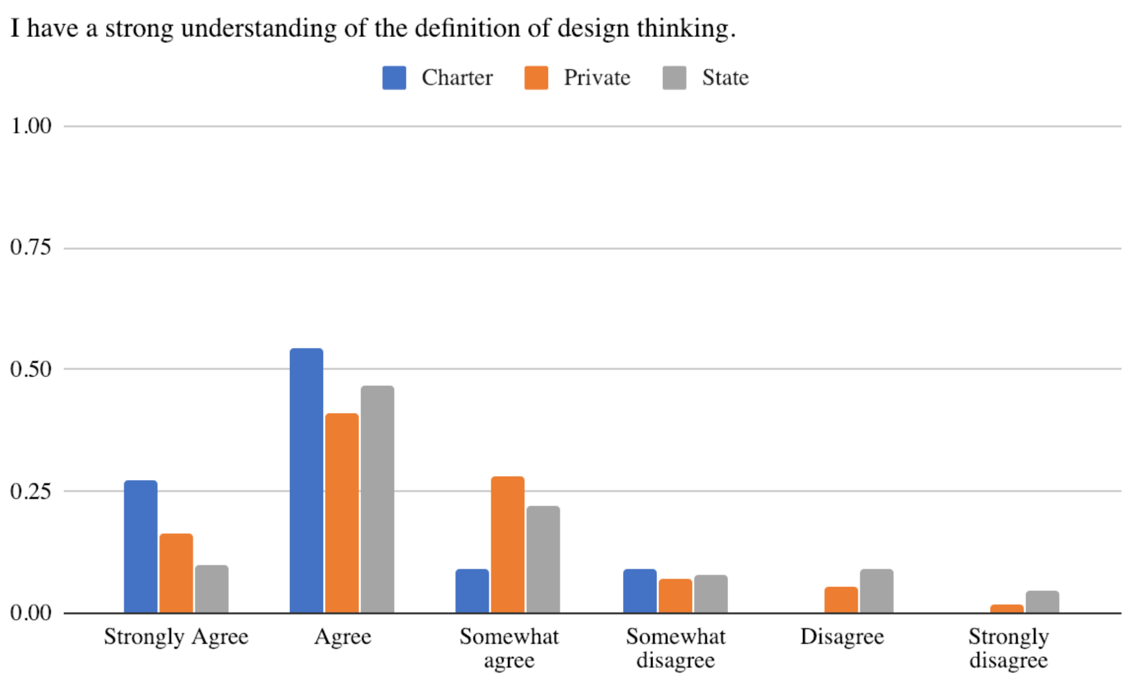


Figure 63. PYP: Stated understanding of DT (split by school type)

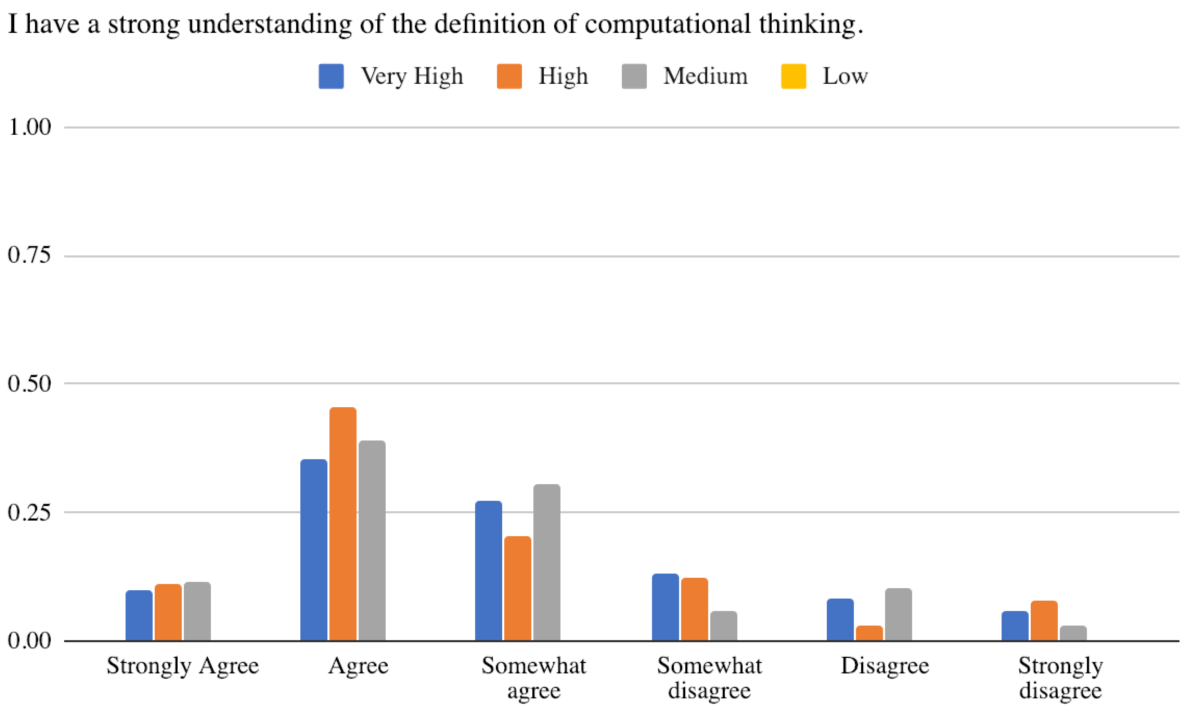


Figure 64. PYP: Stated understanding of CT (split by HDI)

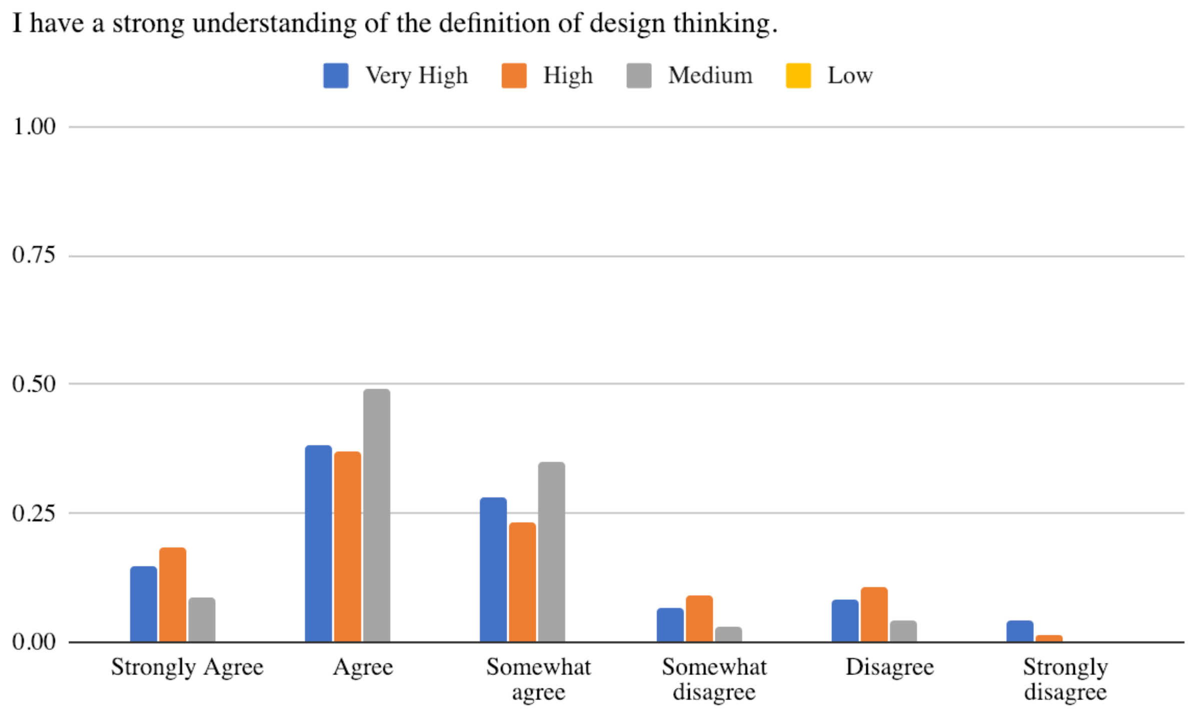


Figure 65. PYP: Stated understanding of DT (split by HDI)

Fostering Computational & Design Thinking in the IB DP, MYP, and PYP

Appendix E

Sample of Teacher Survey Responses: Implementation and Approaches

Appendix E. Sample of Teacher Survey Responses: Implementation and Approaches

PYP Teachers

Integrating DT

Age 3-6 group

Describe one way in which you have successfully integrated design thinking for your students.	Describe an example of how you could improve the use of design thinking
Construction area with various wooden blocks	*Create more and varied provocations for developing this,*
l'analyse durant les modules de recherche	*Differentiation and accomodate children agency*
During the unit of Animals, the learners were given a problem that an animal could face and they had to find ways to help this animal.	*On peut partager les experiences des autres afin de les appliwuer en classe*
When we asked open ended question for students	*Learners should be more involved in analyzing and open-ended questions and should find different ways to learn.*
First, let kids draw what they want to design. Then, provide materials fo kids to make them.	*In the live life unit the students had the opportunity to plant their plant and record the growth of it, seeing that each one grew at their own pace allowed them to know and respect the differences in the processes*
Throughout the units I seek to develop activities that involve the development of the creativity of the students and that have the opportunity to build a personal result that is in accordance with the objectives	*I can improve it by let them have more accurate image of everything.*
During the Unit about Water the students needed to come up with a solution on how to save water in our school and what people should start doing to keep our water sources clean	*I could elaborate more open ended questions and let students come up with different solutions to problems in our daily routine. Ex: we are out of paper/crayons, what should we do? How? Do you have a plan?*

Students have to design a way to get from point a to b using clear language and steps so the others can follow.	*Open ended problems where students have to think in different ways for solving problems using specific steps and clear instructions.*
I have not done this directly, maybe I have encouraged students to be creative and thinker to find practical solutions to little problems that might happen in the classroom.	*I think this methodology should be integrated from an early age so that the students can improve it.Group activities and free hand given to the student can improve design thinking*
Cuanto trabajan el ciclo de indagación en el exibition	*Antes de explicar algún tema o concepto nuevo, podría generar problemas e invitar a mis estudiantes a pensar en posibles soluciones.*
Applying the agency is a start for design thinking what they want the learning looks like. Agency also applying in their house, especially in working with the home project	*Utilisation du learner profile entre les apprenants*
Quand il y'a un sujet a resoudre , je le discute avec les apprenants pour obtenir une solution donnée par le group.	*Reflecting on their ways of thinking can be challenging in early years. Would love to find more strategies to help them reflect*
Children are taught to self-evaluate or reflect on the things that they have done, what their friends have said, or what they are interested in doing. They created sketches or models of what they have imagined.	*Planificar de manera más estructurada tareas de desempeño teniendo como objetivo la solución de una situación real que se les presente a los alumnos.*
We invite kids to design their own poster,their own show .Students has the right to design what they want to do and how they do it.	*In order to enhence the megacongnition of the children, we can take the children to the art museum, and try to guide the children understand other people's thoughts, and create new art works with their own design thinking.*
I provide opportunities for children to disucss about the inquiry related questions during the circle time.	*During the group avtivity,studens can work together to discuss and design how to finish their task.*
Kindergarten students have learned how to use ipads to draw and create pictures and make video recordings.	*I would like to develop creativity of all my students, even the lowest ones.*
I used fairy tales that had a problem needing to be solved. The children read the fairy tales, chose one, located the problem and used design thinking to solve the problem.	*this will improve when we teach students how to think and not what to think,give or provide them with materials that will provoke their thinking skills.*

Our students in Prep design a moving object and create it based on their plan and reflect on their ideas.	*Il faut intégrer la pensée design dans les modules de sciences sociales comme les relations.*
Durante el desarrollo de las unidades de indagación se utiliza como herramienta el juego trabajo para promover la resolución de problemas, la empatía, la creatividad y el trabajo colaborativo.	
"Creating obstacles courses and maps	
Creating stories through technology"	
working in groups	
brainstorming	
When students participate in group activities they develop social skills, creativity and empathy.	
through inquiry student have to learn problem solving and how to deal with open-ended questions and collaborating.	

Age 7-13 group

Describe one way in which you have successfully integrated design thinking for your students.	**Describe an example of how you could improve the use of design thinking**
My students have had the chance to develop their investigations by using the Design Cycle as a tool that helps them to organize their work in order to find a solution to a problem after investigating, planning, creating, and evaluating.	*Fomentando en los niños el ser más curiosos, tomar la iniciativa de ampliar e investigar más los temas tratados. Esto ayuda a que los niños sean mas conscientes de lo que pasa a su alrededor, para que en un futuro pueda tomar las acciones pertinentes.*
"planning, creating, testing and refining a design e.g paper plane	*Based on feedback, students might need to make some changes to improve their solutions.*
planning action to be more sustainable"	*provide students with meaningful problems that addresses people's needs /try to make students' thinking visible most of the time.*

Planning and mapping out their ideas for writing, projects, and maths.	*I could present it as a model, just the way we present the Engineering design process and the scientific method. I would begin with the vocabulary at the beginning elementary levels using immersion strategies and TPRS.*
Au cours du travail sur un module, on discute avec les apprenants sur les actions qu'on pourra entreprendre vis a vis de ce module.	*Collaboration between Art and Design teachers from High and Middle school.*
students design posters to show the opportunities available for children locally and globally.	*To have any level of support from our coordinator. He doesn’t even attend planning meetings*
In our last unit of inquiry, students were required to design a warning system using light or sound. They planned their design, tested and appraised it, before making adjustments to improve their warning system.	*More in depth thinking and problem solving that is stemmed from their own understanding and action.*
I use the concept of design skills through the emphasis on STEAM. Students are thought cognitive skills to inquire, question, analyze and create connections to the learning.	*Students make a model of a landform with labels.*
Ex. How we organize ourselves unit: students had to desing a proyect miming an animal with a purpose related to solve the trash problem in the society.	*Open ended tasks*
Asking students to design a mobile holder where the person can be hand free and face time with family whilst s/he doing work around the home.	*Help students to be brainstormers ie encourage them to come with many, wild, ambitious ways to solve problems without questioning it.* *Another way would be by iteration. Letting students make changes after receiving meaningful feedback.*
Students used a currently community group that was not promoted for all gender, social, cultural etc types. They then created a way to incorporate everyone.	*Providing space, open minded_ness and inquiry through possitive feedbacks and safe environment are some ways which help in designing thinking in learning and teaching process.*
They were able to design a complex machine using one or more simple machine in a very creative manner.	*The Freedom to Learn everyone has different learning style* *Encourage Project-Based Learning* *Encourage Collaboration* *Include Professional Development* *Make a Mess.*
By asking them to design questions on how to inquire their classmates in a pair or group working strategy on	*look for solutions to solve problems in the amount off plastic used and have students track their progress. Also have*

the topic they required to, as well as encouraging them to collaborate together throughout the subject.	*students come up with solutions to how we treat one another.*
"We made a newspaper about the environmental problems	*We could focus on one problem and keep on working on it according to the design thinking cycle until we reach the optimum solution.*
The class made their own shopping bags	*During the unit "healthy choices", students should design a healthy meal but they are not solving a problem.*
With messages to the earth"	*While investigating how plastic bags affect our planet, we could bury some of them as well as some of the paper or cotton bags, to see what happens to soil and plants around them.*
When discussing social issues: ???? ?? multi ethnic, multinational, we give questions and create responses about all social developments at the moment. The pupils give answers from their own experience and there is no wrong answer.	*Give students an open-ended task with several possible outcomes. Students can choose how to approach the problem(s) and work on or offer potential solutions to the problem.*
During the unit STP titled "Save the Trees", after finding the causes of deforestation and their effect on the human and the environment, the students collaborated on finding solutions to preserve the forests.	*By including a design challenge within each of our units of inquiry. Currently there are a few units that lend themselves readily to using design thinking like How the World Works.*
My students made the scenery for the play. Made from scrap materials basis for theatrical performances."	*Increasing collaboration further and follow up on applicable prototypes with experts.*
Our students have created an exhibition of models "Water resources of Russia" and posters "take Care of the water!"	*La capacitación docente es básica. El Programa de indagación diseñado e integrado, que contemple estos tipos de pensamiento es clave. Metodologías como el aprendizaje basado en proyectos, son adecuadas.*
My students created scenery and mockups for theatrical production.	*By giving more problem solving questions and open ended questions*
By having students engage in activities that require them to work through the design thinking process. To address design challenges and improve solutions over time.	*Introduction of creating Makerspace, STEAM activities and BP challenges around architecture, building and creating*
Students were well engaged in their fifth unit of inquiry, Cities. As they created their own design of cities, collaboratively. They had problems in the way of crafting	*integrer la technologie dans la classe*

the city, but they were able to solve the problem brilliantly.	
Group work, joint preparation for the final event (educational game)	*integration of subects including math*
Llevar a cabo el desarrollo sistemático de un proceso para encaminarlo a un objetivo.	*This year I plan to introduce and provide opportunities to students with various Stem based challenges which of which few will be integrated with creative writing.*
"When We do Stem Challenges in each unit.	*By making such real life problems so they can develop practical and innovative solutions for your problems.*
Design thinking has been integrated throughout our programme of inquiry, including an example in Prep where students consider the properties of materials to design and evaluate a bridge for the goats in the Three Billy Goats Gruff.	*the students must have a very excellent skills in the using of computers ,in this way they can improve it.*
With regards to taking action in every unit of inquiry, students are asked to identify a problem in their environment and then think about how we can go about solving that problem, keeping our audience in mind.	*Levando a cabo más retos en equipo a los alumnos em distintas materias, por ejemplo elaborar un juego de mesa para aprender multiplicaciones.*
The Math program out school district adopted is inquiry based and conceptually focused. It is also supplemented with more traditional skill instruction when needed. We integrate the math when we can, but math is not integrated in every unit of inquiry.	*Through collaborative planning opportunities with MYP/DP design teacher.*
Al pedirles un trabajo de investigación en equipo ellos ponen en práctica el pensamiento de diseño tanto para colaborar en el objetivo como para el producto que se les está solicitando.	*Open ended inquiry* *Student led inquiry*
	A través del arte creativo en cualquiera de sus expresiones.
During a unit about exploration. The students used design thinking to plan, research and design a piece of artwork that reflects a specific form of exploration.	
Use the design cycle	
use of art and creativity	
Durante la planeación colaborativa, se buscan estrategias pertinentes para el logro satisfactorio del pensamiento de diseño	

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Use the design cycle	
use of art and creativity	
Durante la planeación colaborativa, se buscan estrategias pertinentes para el logro satisfactorio del pensamiento de diseño	

Integrating CT

Age 3-6 group

Describe one way in which you have successfully integrated computational thinking for your students.	**Describe an example of how you could improve the use of computational thinking**
obstacle courses - following directions	*pitched at a lower level for the younger children - break down skill sets to teach these*
La presence de l'ordinateur en classe	*Implementar un centro de aprendizaje con el uso de classmates con programas correctamente seleccionados de acuerdo a nuestra unidad.*
It is limited when dealing with 3-4 years old learners.	*Use technology in learning and teaching*
Give kids different shapes to find them in their lives.	*En lles aidant à utiliser l'ordinateur pour les recherches les jeux de maths*

We have not worked much with computational thinking, it is worthwhile that we integrate it with learning	*We use the ipads but we can integrate the computational thinking into more activities*
Teaching numbers and patterns by using colourful wooden blocks.	*By making connections with the real world and develop strategies for implementing the same.*
decomposition - breaking down a complex problem or system into smaller, more manageable parts	*developing a step-by-step solution to the problem, or the rules to follow to solve the problem*
Breaking bigger problems into smaller parts, easier for little children to follow and understand	*Planning a situation/problem that children can solve step by step*
Once students are able to give you instructions in steps hey are using patterns to solve or achieve the objective.	*Asking students in all subject areas steps and clear language to follow. Procedures*
Cuando los niños trabajan actividades con el programa robomind donde dan sus primeros pasos en la programación.	*It will be beneficial for the students if very week a group of students are given a task in which they will use their computational thinking and share it with the rest of the school in the form presentation.*
Mathematics is the most difficult subject for the student, the role of the teachers on this area is giving opportunities with strategies in solving their problems (with tools or not)	*For example, to share their snacks with them by providing mathematical language, such as "you are taking quater or half of the cake" or "could you please distribute the fruit to our class. we have 15 children today".*
While learning about pattern.we used the pc while learning what is pattern , where we can find it and how to create it and at last how to extend pattern.	*In the unit of product,students get the information what kind of things peopel would like to buy,and then they analyze the data ,at the end they make the desion to make jucie and handcraft to sold.*
Block play , Lego play, pattern play , are successful ways for integrating computational thinking	*I would more carefully observe the children's understanding level about this concept and try to make adjustment based on the children's needs.*
From my own perspective, for 3-6 years old children, computational thinking is invovled in children's everyday lives. We can involve computational thinking from many actions from what we do.	*Sería importante que en varias asignaturas resuelvan problemas por medio del uso de algoritmos. Los niños pueden adquirir las habilidades pertinentes para que se les facilite el pensamiento computacional.*
Students can use comptatunal thinking when do the task,studend get datas,and sort out and use data to make design.	*Creating stronger stand alone units of inquiry for mathematics*

We have been using chrome books to improve math skills.	*I think we could integrate more technology in the classroom.*
Sorting date of personal identity - graphs, eye and hair colour.	*Breaking down problems more into steps, during science experiments.*
Making number stories *Organizing race teams for p.e.* *Building towers and cities*	*integrate some computational thinking into our units of inquiry.*
how i integrated computation in class is when we are researching some materials in the computer and engage students in the process.	*Simple math and coding*
By using problem solving	*Thinking more about cross curricular planning*
Through technology	*With more collaborative lesson planning with all grade level teachers per semester before beginning a Term.*
En el uso del iPad	*Build on different ways students can work on problem-solving while utilizing technology.*
'-Practice addition and subtraction with food seeds such as chickpeas and beans. *-Puzzles* *-Xtra-Maths(online platform helps children to practice their maths skills)*	*Ask the students to create their own game with their own rules .*
When they see a pattern in their environment, and then integrate it with subjects such as math where we have patterns too. They are curious about weather patterns,	*Integrándolo en sus clases diarias.*
	Peer learning and group activity.
	pitched at a lower level for the younger children - break down skill sets to teach these

Age 7-13 group

Describe one way in which you have successfully integrated computational thinking for your students.	**Describe an example of how you could improve the use of computational thinking**
Our students have been able to use technology (ipads, Chromebooks) to learn, practice and assess their skills in Math, English,UOI, as well as in other areas (for example: SEL).	*Maybe it would be good to include experiences like Genius Hour more often.*

Cuando los alumnos resuelven problemas matématicos engrupo y de la misma manera son capaces de formular sus propios problemas usando los conocimientos adquiridos.	*Using mind craft to create a town*
Through maths, the children solve problems using systematic approaches	*Students can follow the steps of computational thinking to come up with a written algorithm for their exit routine.*
By utilizing the natural inclinations of my students to explore and play, and by encouraging problem-solving skills	*travailler plus des cas authentiques , des problematiques de tous les jours afin de trouver des solutions*
students listen to stories that addresses human issues and try to determine the problems and find solutions to them.	*focus on critical thinking: ask questions that allow students to think in depth (why-how) .*
Students have spent some time learning how to code which has been a successful example of integrating computational thinking. Generally in Maths, students have used the computational thinking process to generate problems and solutions.	*Having more ipads in the class or having computers class more often.*
Computer games are owesome for children to practice language,math, reading, science,social studies and everything. Group thinking challenges, fill in blanks, corresponding, etc...	*Breaking a complex problem into smaller, more comprehensible steps* *Creative problem-solving* *Debugging* *Logical thinking* *Conditionals (if this, then that)* *Recognizing patterns*
I have successfully integrated computational thinking for my students through worksheets and games.	*Children can be given opportunities to explore different technologies like robotics.*
Games	*use of telecommunication devices, such as a laptop, tablet, mobile phone, and Internet access with defined search of a given topic appropriate to age*
Students were given to find a suitable classroom layout that would allow them to be in comfortable learning environment.	*I think it'd be interesting and helpful to use computer games in order to teach them a broad spectrum of lessons, it would improve on multiple things and not just computational thinking.*
Students had to create one way to collect data during a field trip. They were able to work collaboratively to develop a new way that shows the results of the survey they conducted.	*coordinating between the math teacher and ICT teacher to be able to give the required skills successfully.*

We learned to do the work according to the algorithm, we used concept maps, we did the work ourselves and checked them according to the algorithm.	*Through the concept map, students can calculate the most important and minor. And be able to use it in a certain area of ??knowledge.*
Trabajar con tablets en actividades matemáticas.	*Through the creation of concept maps students master a certain area of knowledge*
The students are given an open-ended problem-solving task approximately every two weeks. The students try to solve this and we discuss the methods for solving the problem. Computational thinking is also built into the trans-disciplinary inquiries.	*Through the creation of a concept map, students understand and master the main and secondary in a particular area of ??knowledge.*
Using flow charts to show cause and effect in natural disasters	*In the classroom, I often make a map of concepts through which students learn to see the problem and can then build an algorithm for research. Also, students learn to formulate questions for the expansion of knowledge in this area.*
Problem-solving in Math is a collaborative activity in my class. Pose the problem & seek solutions in groups. Similarly in UOI.	*Más software educativos entretenidos y llamativos para los estudiantes. Capacitación y actualizaciones para los docentes.*
One way that I have successfully integrated computational thinking for my students generating scenarios that provoke learners to make solutions.	*Using computational thinking in a wider range of real-life situations.*
Students had successfully used the the computational thinking process in their last unit of inquiry, environment. As they used computer programs to present and solve the problems related to their presentations.	*By being more deliberate in finding ways to incorporate computational thinking across units of inquiry.*
Creating problem situations, finding different ways to solve them.	*Work with tables, creating algorithms.*
preparation of research presentations	*provide more autonomy in research*
Creating cartoons, presentations.	*Classes computer science and robotics.*
Realizar ejercicios prácticos y reales de acuerdo al programa.	*I think we should have more lessons on how to develop tech skills*
We make students research and use digital citizenship constantly when they use tech tools.	
	Compartiendo experiencias con colegas.
Dando estructuras modelo a los alumnos	*Using apps to do picture coding. I used Scratch when teaching cartesian*

	coordinates. Students designed programs to slide, rotate and turn a shape across a cartesian plane.
A traves de la generación de contenidos usando aplicaciones en los proyectos realizados en clase.Pero hay mucho que aprender.	*Tendría que instruirme sobre esto. Por ahora lo veo en la instrucción en matemáticas.*
En la enseñanza de manejo de información, importancia de la organización de sus propios aprendizajes o documentos	*While giving inquiry for my current topic Role model, I can tell my students to use Abstraction(remove details and extract relevant information from the internet).*
When we look at a unit problem (big idea), as a class we break it down into smaller part and then create a step by step plan on how to solve the problems. at the end of the year during the exhibition, they then get to do it by themselves.	*By making class discussion so that students can share their problems and think how to solve them.*
Through mathematical invesigation	*By incorporating more situations where the children learn to solve problems on their own.*
Problem solving and reasoning have been integrated across the curriculum areas in the classroom. Daily life skills have been included in many subject areas this year. Students are consistently problem solving and reasoning.	*i don't know!*
While doing the unit, "how we organize ourselves," the students learnt to create their own sums along with the calculation of profit and loss in business.	*Realizando instructivos para soluciones de problemas matemáticos.*
Organize their time during the week to accomplish their home learning tasks.	
By integrating computational thinking students are now able to solve problems by themselves	
Presenting video clips that show what artists work on and how they develop their vision to communicate it helps students to understand how to solve their problems during their process of work to achieve their objectives.	*Students can be given social causes and practical situations to understand problem solving practically in and out of the classroom environment.*
Presenting video clips that show what artists work on and how they develop their vision to communicate it helps students to understand how to solve their problems during their process of work to achieve their objectives.	*Con actividades enfocadas específicamente a desarrollar en los alumnos cada una de las etapas del pensamiento computacional, para posteriormente realizar actividades que abarquen todas las etapas*
math inquiry	

looking for patterns in math	*Students can be given social causes and practical situations to understand problem solving practically in and out of the classroom environment.*
During the exhibition- students looked at how algorithms can be applied in their learning and other real-life situations.	*project based learning*
Desining surveys. *Organizing information using Excel, power point as a technology teacher the use of digital resources are a priority.*	*implementando circulos de lectura, reflexión, entre otras actividades en la que los alumnos puedan realizar conexiones entre los conceptos*
Paleolithic people: creating maths problems about the expansion of agriculture regarding the fields they had available	*It would be good to collaborate with MYP/DP Computer Science, Physics and Mathematics teachers during planning meetings.*
Our students have been able to use technology (ipads, Chromebooks) to learn, practice and assess their skills in Math, English,UOI, as well as in other areas (for example: SEL).	*Give then open ended queation during mathematics, and used reasoning skill to find various solution of mathematics problem.*
Cuando los alumnos resuelven problemas matématicos engrupo y de la misma manera son capaces de formular sus propios problemas usando los conocimientos adquiridos.	*Integrating digital resources in all subjects.*
	Students can be given social causes and practical situations to understand problem solving practically in and out of the classroom environment.
	While doing inquiry we could focus more on abstraction(remove details and extract revelent information)

MYP Teachers

Integrating DT

MYP Design

Describe one way in which you have successfully integrated design thinking for your students.	Describe an example of how you could improve the use of design thinking

All my MYP Design Unit are centered around Design thinking, from Gardening (which allows multiple iterations), to woodwork or 3D-printing.	*Presenting students with authentic problems*
students look at some existing products and try to innovate them. Target audience and their requirements are the focus of discussions, with problem solving at the core of Design thinking.	*Design Thinking should be incorporated through ATL skills.*
Establecer un scope&sequence a lo largo de todos los años de aprendizaje (de 0 a 17 años) para alcanzar habilidades y competencias asociadas al pensamiento del diseño y computacional	*By creating problems which has thought provoking design situations.*
The IB design cycle itself IS design thinking! Students understand how the process they follow, to produce an effective working product at the end of the project, must iterate in order to be successful.	*Include more iterations to show how things can continuously be improved upon in order to achieve a better outcome. Sometimes we are constricted by internal deadlines that don't allow for extending the development phase.*
Designing thinking is easily incorporated in the teaching of design. At our school, we habitually use the design cycle and embed it to all the activities and tasks.	*Sometimes the backwards design approach can be used to deepen the use of design thinking*
Allowing the students to problem solve their own ideas to present their positive and negative elements.	*Dedicar más tiempo a los procesos de indagación y análisis, puesto que son la base de la investigación que conducirá al adecuado desarrollo del proyecto*
Los alumnos desarrollan su creatividad y colaboran para la resolución de proyectos y diversos problemas	*The assessment criteria demands quite extensive research and inquiry, students thrive better by testing and trying out. We could improve their design thinking if we would have greater resources for students to use, e.g disassembly and assembly.*
We practice Design interest-provoking writing and critical thinking activities such as brainstorming and mind mapping and incorporate them into the design course in a way that encourages inquiry, exploration, discussion, and debate, with Engaging Ideas.	*J'aimerais plus insister sur la métacognition, le processus quand ils réalisent les projets. Toutefois, je ne veux pas alourdir le travail.*
When students have been called upon to consider what a logo or a prototype design to further the UN's Global Goal Initiatives by following the design cycle. This is one way that I have integrated design thinking.	*Perhaps by making more obvious reference to it while teaching, so that students are more aware that what they are doing is fundamentally related to design thinking.*
We follow the design cycle and keep referring back to use our research to find some more solutions and invent new	*Applying a much more specific DESIGN THINKING method with the specific*

ways if possible. In general students are exposed to relevant topics and their design issues to start thinking in new ways.	*phases of EMPATHIZE, DEFINE, IDEATE, PROTOTYPE and TEST, instead of the Design Cycle stages...*
By using the MYP Design cycle approach to all project work, students are constantly referring to the cycle to make further progress.	*Providing students opportunities and activities to create inquiry questions.*
Creating relevant and real context situations that encourage students to understand the user and fail as fast as possible to create meaningful learning experiences.	*Design thinking is a process to solve real problems creatively. We follow design cycle to solve real life problems. I think in all the subjects teachers should start the topic by posing a problem in front of students.*
Students Will have the chance to improve earlier parts of the designprocess to improve later parts using a roadmap to track the critical thinking process. The whole curriculum is bases on critical reflection and logical follow-up.	*Design thinking is not something that can be enforced in teaching, but we can always encourage the students to think in that direction*

Individuals and Society

Describe one way in which you have successfully integrated design thinking for your students.	**Describe an example of how you could improve the use of design thinking**
Implicitly this may have been done, but it is something I know very little about.	*solutions for conflict resolution- group activity*
I have asked them to design and create an Augmented Reality app that worked with paintings the students had previously created.	*Making the daily tasks more based on student creation and incorporating multiple elements within the problem-solving tasks.*
Al generar e implementar proyectos de beneficio social, pues tuvieron que investigar, planear, implementar acciones, y evaluar.	*Eliminate it*
Integration of designing products that can be useful for eco concerns.	*I could work closer with the Design teacher to find ways of incorporating design thinking to more topics of Individuals and Societies and doing more projects together.*
Designing questionnaires/ interviews and carrying them out for research purposes.	*At the end of every unit we could facilitate and engage the students in creatively designing useful model that*

	can express applicability of all that they have learned.
design thinking in finding solution to pollution,promote sustainable management	*Talk to students about it and provide more opportunities in class for it*
In an IDU with Science and Design the students had to create a product that could help to make farming more sustainable.	*making interactive models and using 3 d printers to construct it*
In designing historic monuments and challenging students to use better techniques for a better structure	*I could make the connection obvious. I also have to find other ways to incorporate Design thinking in I&S other than finding solutions to complex problems. Maybe, it could be part of the action plan for their Cri.B investigations*
Prepare a model of a sustainable city and justify your plan	*More open-ended assessments with products as their goal.*
I don't find it relevant in in my subject	*Usamos bastante el pensamiento de diseño, pienso que se podría mejorar si nos reunimos todas las profesoras de individuos y sociedades y lo planificamos para tratarlo de forma gradual, profundizando de año en año.*
Students make projects in which they think of issues happening in their society. Through their projects they intend to promote thought or promote change in a creative way. They come up with their own solutions and ways to communicate themselves.	*When I looked at the students'homework, I found that they misunderstood the concept of globalization. i asked them to look up the definition of globalization and organized a discussion in class, then let them revise their homework.*
Through functional #sdgs *Through community service action , through IDUs*	*Not sure*
Implicitly this may have been done, but it is something I know very little about.	*By understanding more in depth only then will I have a complete understanding of this concept*
I have asked them to design and create an Augmented Reality app that worked with paintings the students had previously created.	*Explicitly mentioning the concept in the I and S guide*
Al generar e implementar proyectos de beneficio social, pues tuvieron que investigar, planear, implementar acciones, y evaluar.	

Mathematics

Describe one way in which you have successfully integrated design thinking for your students.	Describe an example of how you could improve the use of design thinking
Our statistics unit required students to collaborate on and generate methods for problem solving to complete their assigned work.	*By introducing more relevant topics*
When I was teaching the circles. I asked them to make the twitter logo using the circles. They were amazed at how can it be possible designing a logo (bird) using just circles.	*Design thinking can be improved by using criterion D- Applying mathematics in world contexts. Solutions to real world issues can be discussed by proposing plausible designs of products, systems etc that incorporate certain mathematics concepts.*
Les projets Design sont fait en collaboration avec les autres matières et font partie intégrante de l'ensemble des matières	*Making the process more explicit, so trying a problem as a group and realising we need to refine the method we are using.*
En un proyecto interdisciplinario con tecnología en el que mis alumnos tuvieron que diseñar un recipiente para gelatina	*By giving an open ended questions where the students can do some research and based on their findings give the conclusion and a strategy to improvise the situation*
By posing the scenario and students empathise and identify the problem, then analyse and develop prototype and test the solutions	*Faire plus souvent des problèmes ouverts ou projets en équipe pour qu'il y ait davantage d'interaction entre eux pour s'entraider et se donner des idées nouvelles de résolution de problèmes.*
no design thinking has been integrated	*Look more at the application of design thinking within tasks that link a real life example to mathematics.*
Faire un projet de programmation 3 D en lien avec la création d'un parc municipal a permis aux élèves de travailler le cycle de conception et de comprendre le design.	*It can be extended in modelling a real life situation/product that will help them understand the use of design thinking.*
Designing the best container to hold cylindrical shaped products in relation to the maximum volume.	*Integrating more real life examples to make the concepts easy to understand by students.*

For Math when there are activities or assesments, I integrate the elements and process of design thinking specifically when they have to define a problem,go through an experimental phase and eventually work on the product or output.	*by integrating more project based learning and dividing the project in different steps and algorithms*
I don't know the design thinking	
Role play of a logistician for a computer manufacturing company which must supply raw materials to suppliers and transport suppliers products to central location for completed assembly.	
Creating iterations of the design of a new school facility, based on real life application.	

Sciences

Describe one way in which you have successfully integrated design thinking for your students.	Describe an example of how you could improve the use of design thinking
Design being a project based assessment, the units are developed in such a way that it allows students to mostly be creative thinkers and at some point critical thinkers while creating a solution.	*Collecting data on how well students relate in their roles within their group*
designing aluminium boats to test Newton's laws, displacement and buoyancy	*Open ended questioning, motivating students to be innovators, display some existing products to guide weaker students.*
Donner plus de tâches ouvertes où l'élève doit trouver une solution	*Giving more open ended tasks to students.*
Group projects in which students have to build a model to show how they would address the limitations of a human illness or disease	*Doing more hands on modelling activities*
We design Goldberg machine, roller coaster and fridge bag	*Solve problems by themselves, guiding*
En ciencias tenemos los criterios B y C que se alinean perfectamente con el pensamiento de diseño	*Cuando se otorga estímulos a los alumnos durante el proceso de diseño, para establecer el uso de un fenómeno científico con la cotidianidad y necesidades del entorno.*

For example, in the chapter of the thermal energy transfer, I require students to apply the knowledge about thermal energy to design a house to maximise the conservation of thermal energy in a house	*By giving projects to students which involves them using design knowledge to design "Green City"- that uses all environmental friendly components*
On a jumelé les périodes de sciences (mon cours) et de design pour un des projets du cours de design.	*The final prototype is always not clearly formed and the solutions are not tested. There is only a proposed set of solutions. I think the last part of design thinking needs to be given more thought to.*
During the project work by the students they used design thinking to prepare successfully a solar powered car which required designing the car with correct choice of material and and design to facilitate the car to function well	*By making use of current topics like 3D imaging for Biotechnology.*
We collaborated our unit with design to infuse MS Logo with sciences, it went out really well. Students connected the technology to create a prototype of plant and animal cell.	*By giving more open ended problems with more than one correct methods/solutions.*
Let students observe more in life, find a phenomenon of interest, define a problem, design an experimental research to solve this problem with by processing data.	*Al poner más situaciones problema a resolver en clases o cuando los alumnos deban analizar problemáticas de ciencias, a nivel local y nacional, y deban proponer proyectos para solucionarlo.*

Integrating CT

MYP Design

Describe one way in which you have successfully integrated computational thinking for your students.	**Describe an example of how you could improve the use of computational thinking**
Mini games from "hour of code", or a robotics Unit, where students have to code a robot to navigate a maze or knock down objects in an order.	*Teach a different subject than MYP Design. Luckily, I am also a DP Computer science teacher.*
Students are often given design challenges where can are given scope of representing the solutions as algorithms. The design ideas for these are developed with iteratively checking the outcome.	*Include programming concepts in MYP learning and develop a curriculum to teach the course like DP computer science Course. A structured curriculum with study programs is a must.*
Video game design. Hour of Code	*By giving students more open ended problems and opportunity to organize and analyse data.*

LA integración del pensamiento computacional en el colegio se lleva a cabo mediante el diseño de un Scope&Sequence que abarca a todas las etapas educativas.	*By introducing more programming units*
We do unit on Robotics using Lego EV3 , this unit help us to introduce computational thinking is a small way. We teach problem solving through flow charts, algorithms, block programming, iteration.. etc.. but is limited to just this.	*maybe by adding more units focused towards computer science/coding*
By allowing the students to solve the problems by themselves and applying the four pillars of computational thinking	*I could use more opportunities to allow pupils to "fail" which helps them to understand the processes they must follow in order for "success".*
Attempted to reach programming skills at all MYP levels. Used robotics, arduino and Raspberry Pi.	*Students should have a foundation of comp thinking skills starting in the PYP. With a clearer defined continuum, skills and concepts can be developed.*
Teaching digital design has enabled me to integrate computational thinking as a basic method. I introduce my students to software that enables them to model and create a product for their design project.	*El pensamiento computacional es la base de mi materia, se pone en práctica en todos los procesos, inclusive en la puesta en marcha, evaluación y replanteamiento de mejoras al producto final*
El planteamiento de los problemas a través de algoritmos permite identificar de una forma más sencilla los elementos componentes del mismo	*Showing students how designers and inventors begin their thought process and the completion of a well planned product.*
Exposing students to different platform to invent new products and look into ways of designing games.	*Plus de temps, plus d'intégration.*
Within the MYP design cycle there is a planning component that relies heavily on computational thinking. Specifically, it could be using algorithms, or Gantt charts to visualise practical processes.	*Deliver a formal lesson on the use and creation of algorithms. I aim to introduce Python programming at middle years but I feel the project based approach of the IB MYP program limits this.*
Defining and developing units that encourage students to use SCRATCH to create their final digital design outcome.	*Create a major number of units that allow students to explore different digital design tools, programming skills and e marketing strategies.*
I have tried to incorporate cumputers into design such as web sites, digital design and so forth as to have students use computational thinking.	*The user of cad software for accurate 3d modeling*
	Computational thinking provides different approaches to problem-solving

	through algorithms, patterns, and logic writing, etc. MYP design students can choose to create solutions by computational thinking.
	By giving the project to a group and asking everyone in that group must participate to construct the complex project then every student will try to complete their own task by using their computational thinking strategies.
	once I use it, would be able to comment on it.

Individuals and Society

Describe one way in which you have successfully integrated computational thinking for your students.	**Describe an example of how you could improve the use of computational thinking**
We went on a field trip where the students had to find an algorithm to calculate the number of trees and plants present in that specific biome.	*Concepts needs to be more highly embedded in my day to day curriculum and students need time to learn what a concept actually is.*
Giving them text about population growth and then asking them to make a graph based on this	*won't*
I haven't.	*I could use more support from the IB programmes in order to find ways to incorporate computational thinking to my subjects, because I find it a little hard to do so in Individuals and Societies.*
Aucun. J'aurais besoin de formation à ce sujet.	*vincular contenidos eticos con proyectos que requieran un diseño en la realidad para impactar positivamente a una sociedad.*
I use the unit concept to design the activities both formative and summative. Daily, I integrate that concept, such as change into the lesson.	*No idea.*
Using digital timelines and graphing tools.	*Ne s'applique pas.*
In the assigned research task students while conducting survey may use computational thinking.	*make it more project oriented*

this was in for example to the calculation or understanding of the GDP, unemployment, HDI indices calculating and/or anderstending	*I need to see examples of computational thinking being successfully integrated in I&S and need to see evidence that it has benefitted students. This will enable me to take this forward*
Students to some extent are able to use spreadsheets in quantifying data collected during n investigation and use these to analyse results. Most effective during interdisciplinary tasks IDU between Math and I and S.	*Need training for the same*
Identify a problem in a local area, collect and organise data and represent to identify patterns and trends, identify the basic problem, propose a solution, evaluate the plan and appraise it	*Actively expressing to students the need to break down issues into smaller steps and encouraging the use of reason more explicitly*
None	*Doing research on its place in MYP Humanities*
giving smart project on traffic congestion	
	Explictly mention the concept in the guide.

Mathematics

Describe one way in which you have successfully integrated computational thinking for your students.	Describe an example of how you could improve the use of computational thinking
Estimation problems, Fermi law examples etc	*When the example is too big I will tell my students to break it into the small pieces. and solve one by one.This is the way of improving decomposition (computational thinking)*
When students were introduced to algorithms in class	*Buscando herramientas que permita un desarrollo en el pensamiento computacional, utilización de herramientas digitales para el desarrollo de nuevas habilidades.*
Algorithm based tasks	*I think i need more understanding of integrating computational thinking into my lessons.* *Probably attending workshops or webinars on that .*

We didn't actually use computational thinking	*The best way to improve the use of computational thinking in my teaching would be to use better tools in the form of computational applications (eg, Excel) and implement this thinking in each Unit*
Maths is about alogrithms, we teach them steps to solve equations. You need to know the steps you do and follow them. We also have a specific section of the framework about algorithms.	*Allow students the time to self teach more*
L'appropriation de logiciel de programmation avec les élèves permettent de travailler des problèmes complexes et la pensée créative. L'Utilisation de scratch, blockscad 3D, et desmos avec les jeunes est un bon exemple	*Allow students the time to self teach more*
Not able to recollect	*Students collect data, list charts, calculate*
I have not done	*Incorporating computers in the class. Technology lags in every curriculum. No textbooks that incorporate 21st century technology. We are still using calculators.*
computational thinking was used in solving an algebraic task that used elimination method to arrive at the solution.	*I could improve the use of computational thinking in my teaching in require the use of abstract representations.*
Real career applications of the mathematics design in action.	*By integrating digital technology and simulations in investigation tasks*
I have successfully integrated algorithmic solutions in equations and simulations.	*When the example is too big I will tell my students to break it into the small pieces. and solve one by one.This is the way of improving decomposition (computational thinking)*
we use different internet tools for problem solving and checking right answers, we also try to use graphs, pictures, trigonometry tools	

Sciences

Describe one way in which you have successfully integrated computational thinking for your students.	Describe an example of how you could improve the use of computational thinking

Not been able to do so	*I need to learn more about this myself before I am able to improve this in my teaching*
Using 'Minecraft' to create interactive models of the periodic table	*I need to have more partially completed worked examples ready.*
At the end of each unit, he students are supposed to make a mind map to link the topics covered in the unit and the global context.	*More time could be spent with strategies - students who are new to interpretation have trouble understanding what is expected and then how to analyse the data vs evaluate the data.*
statistical analysis of data in data based questions.	*Not trained.*
Por medio de prácticas de diseño que resuelvan problemas de aplicación, la utilización de distintos recursos informáticos para el diseño, comprobación (o no) e interpretación de resultados	*If I knew more about computational thinking I would be more creative*
I let students use computer to recorde and analyse the experimental data	*Adding programming such as scratch or swift to the science or design curriculum*
devote time to explicitly reflect upon computational thinking processes, resisting the temptation to drift to purely practical instruction, focus on discrete notions, rather than on continuous ones,	*coordinating with Design teacher*
when students design there own experiments they are logically writing down steps for each of the experiments and reworking on it in case of errors	*Práctica constante del vocabulario, herramientas, estrategias, etcétera, que les permita enfocarse en el pensamiento computacional de manera optima.*
Using Simulations and virtual labs for MYP students	*Through class activities that use computational thinking to create graphs and tables using excel*
using some software to process the data they got in the experiment	*During determination of rate of chemical reaction or for solving problems of yield or percent purity, students were asked to scaffolding steps*
Other than using gamification and video based reflections computational thinking has not been successfully inregrated.	*I could improve the use of computational thinking in my teaching by adding the topic of robotics and programming in Physics.*
	By implementing it very formally with all the steps through well-designed tasks and projects. We can have algorithms for students response look for solutions to

	real life situations like water scarcity, waste management, reforestation etc.
	Will need in depth clarity on computational thinking first. Not sure what I know right now is enough.

DP Teachers

Integrating DT

Chemistry

Describe one way in which you have successfully integrated design thinking for your students.	Describe an example of how you could improve the use of design thinking
The scientific methodology and design thinking are strongly related so pretty much any design experiment uses design thinking.	*Remove some content to allow for the time it takes for teachers to incorporate design thinking into their planning. Design thinking takes a significant amount of time to teach and learn.*
It is integrated through labs, IA and NOS. Different labs are designed keeping various aspects of the IA. For example, one lab is totally on designing and other is on processing.	*Ask open questions. Encourage students to provide answers in a systematic way.*
Design thinking has been used during my chemistry classes during preparations for Internal Assessment tasks. It resulted in good marks received for innovative and well prepared individual investigations.	*By discussing more and more NOS questions to make them aware of the contributions of the scientists and also by discussing the possible solutions of the existing problems.*
In Option D medicinal Chemistry students worked on designing a framework on developing a more sustainable world using principles of green chemistry(using catalyst, alternative solvents etc) and how the problems of 21st century can be resolved.	*Providing open ended lab questions for students to solve*
Giving molecular models to students to create their own design of new allotropes to Carbon... *Investigating Limiting Reagent concept by lab activity(precipitation reactions)* *Using Simulations in teaching(pHets)*	*Put more effort on promoting creativity of students in designing the experimental work.*

Through internal assessment. students have to design a chemical solution to a problem of their own choice. To do that need to collect relevant information, analyze the problem and design and try number of solutions .	*ToK in the subject as such does enhance students design thinking skills. A group discussion on a current issue which links with the topics in the syllabus can be a way to improve the use of design thinking. e.g. nuclear chemistry - Korea issues.*
Allowing students to develop investigations. Improving them as they proceed from day to day.	*Each student should have their own devices to be able to work at their own pace*
I gave students a scenario involving a pharmaceutical company and they had to come up with solution to the problem.	*Giving a problem and the students need to design how to answer it, most of the time the problem is a Chemistry Lab activity that they need to design.*
	Proporcionando al grupo de estudio situaciones integradas a las cuáles para resolver deberán hacer uso de otras habilidades, además de algoritmos. Por ejemplo, encarar con creatividad la elección de atajos cognitivos.

Computer Science

Describe one way in which you have successfully integrated design thinking for your students.	**Describe an example of how you could improve the use of design thinking**
When teaching programming we teach the iterative process of design thinking and prototyping. Students have to develop write ups outlining their design, planning, prototype and then actual solution. This is then extended to the IA.	*A better outline from the IB on what they expect in IAs in regard to this.*
Student define a problem, identify a solution and then design an interface layout for a real client as a process for Internal Assessment for both Computer Science and ITGS. Thus showing design thinking through their IA.	*Giving them structured element in the process of design of software process in the implementation for client's solution*
For the CS IA project, students interview their client(s) for requirements, brainstorm potential solutions, create	*Joint IA work with Design Technology where the final product is a physical one and each students applies different skills*

prototypes, get feedback, and iterate on their designs. Parts of this are repeated for an end-of-year team project.	*(cooperative work). The produced IA are separate, with a shared target.*
I give practical examples involving different principles of design thinking in context when integrating Unit 1's material into my course. Where possible I do this within a programming assignment to build their computational thinking skills.	*Give an example, discuss about the requirements of the IA, understand theoretical aspects of the design thinking, work closely with end-user, try to create best Design for project.*
Creating/designing open-problems for students that make students to think of any possible solution(s), criticizing their solution(s) and try to implement it at the end. Several projects in different fields/context would be made.	*By feeling less rigidly tied to the IB design cycle - it is far too rigid and does not leave room for flexibility for example when doing projects that are not suited to rigorous evaluation.*
The students are asked to develop the UI for a application and then present it to their peers to be assessed against the criteria of Nielsen's Heuristics and Morville's Honey comb model for usability	
Design thinking integrated while catering to the concepts of System Fundamentals and while introducing them to the Internal Assessments.	
When teaching programming we teach the iterative process of design thinking and prototyping. Students have to develop write ups outlining their design, planning, prototype and then actual solution. This is then extended to the IA.	

Design Technology

Describe one way in which you have successfully integrated design thinking for your students.	**Describe an example of how you could improve the use of design thinking**
Design Thinking is a fundamental part of the DP DT course. Allowing students to understanding the design cycle and experiment with design concepts and iterative them allows for problem solving and solutions being considered suitable to fulfill a brief.	*I can improve design thinking by visiting or showing some design studio and some designing sites where designers are solving the problems of target audiences. these examples will inspire them to enhance design thinking skills.*

Se plantea a los alumnos diferentes problemas con condiciones a cumplir y que deben solucionar en grupo, proponiendo soluciones al problema planteado.	*A theoretical Unit on Design Thinking can be incorporated in the curriculum*
While IA is introduced to the students during DP Year 1, students are also involved in understanding the criterion. Each criteria is separately discussed along with individual assignments given to students for further inquiry.	*Perhaps with additional resources, field trips, or miscellaneous activities which actively and specifically involve design thinking.*
The IA requires the students to use the design thinking methodology, but the course doesn't allow time for the pupils to practice the art of empathetic design or ideation as the time it takes to teach the theory content impinges on it	*The present IA is too restrictive in design freedom trying to accomodate an easy life for moderation rather than allowing the students to explore the subject as designers. Creativity is quite frankly inhibited by the assessment structure.*
The way I have integrated it is through design challenges emphasizing empathy and empathic design. Also trying to connect design thinking within the design project. However, some of the Design project requirements detract from the design thinking method.	*more time to be creative and model different concepts*
Cualquier proyecto de diseño que se lleva a cabo involucra el pensamiento de diseño estrictamente. Los alumnos se familiarizan con las etapas propias del ciclo del diseño y por consecuencia usan el pensamiento de diseño.	*More explicit teaching of design thinking strategies*
Realizamos ejercicios que son comunes a ambas disciplinas. Cómo preparar un plato de arroz, paso a paso.	*After-action - after completing I/As in year 1, have students reflect on how they could have used design-thinking more extensively to improve their product design/solution to the design challenge*
I have had some success integrating design thinking with my class however, the students are fixed in their thinking about designing for form and function, not from the perspective of human centred design	*Creo que sería útil que los alumnos experimenten cualquier tipo de proyecto, no únicamente los de diseño, siguiendo los pasos del pensamiento de diseño. Por ejemplo, encontrar la solución a un problema de biología.*
	I would like to use it more with IAs as students start their projects so that the nature of the project is more authentic and based on actual local target

	audience needs that haven't been tackled before making the approach more original.
	Encontrando mejores ejemplos de desarrollo para ser presentados ante los alumnos y comprendan los beneficios de esto.

Geography

Describe one way in which you have successfully integrated design thinking for your students.	Describe an example of how you could improve the use of design thinking
I think we do this a lot without necessarily being aware of it. For example, students completing IAs (in both ESS and Geography) take a very independent path which often encounters problems to be solved and modifications to be applied.	*Based on an opportunity, develop it stage by stage, scaffolding style. Differentiation could be also helpful, however amount of teaching hours does not allow to implement it in full scale.*
not possible due to time constraints in a deep and broad curriculum with conceptual learning and nexus thinking to integrate, teach, assess	*Further application in evaluation of responses in dealing with policy evaluation needed in the course*
La manera de integrar el pensamiento de diseño , es los trabajos colaborativos en investigaciones que permitan responder una pregunta del conocimiento, tal vez realizando un juicio a un líder político.	*Using project-based learning strategies. This helps students to be creative and develop a strong sense of critical thinking and other skills like analysis and problem-solving.*
During IA study time which is more practical on real life situations, research on the environmental,population,food and health,urban environments,water scarcity by trying to compare given situations and how man has affected/influenced the occurrences.	*By using examples and allowing students more time to consider solutions, which stakeholders would benefit, evaluating the validity of this, then trying to find examples that would support or refute the ideas.*
When deconstructing management strategies (e.g. river flooding/renewable energy) to look at how it is	*Urban settlements and any kind of built (designed) environmental system discussions. A key concept is*

constructed, who it impacts and then evaluste its overall effectiveness	*"sustainability", and any application of this concept needs an understanding of the principles of design thinking.*
Did a 'group 3 project' whereby all students had to create an interactive display/ presentation of a particular theme (eg 'colour') and link it to an aspect of the course they have studied.	*I think that I should first study this problem, because my knowledge about design thinking is very small.*
Students have to create models to represent the data they find on their fieldwork investigation for their Internal Assessment (IA) and we discuss at length different ways to draw in an audience through the design of the data display methodology.	*Par mejorar el pensamiento de diseño pienso que se puede desarrollar la creatividad del alumno disfrutando el proceso de enseñanza mediante sus propias habilidades y destrezas.*
decision-making and problem-solving exercises. These need to part of IB summative examinations or forget it.	*More hand on / physical model making with less teacher input. Also more individual design thinking tasks rather than group activities. I would also like to do more presentations where pupils can discuss their ideas.*
The use of wicked problems, and the mitigating solutions of CC	*Provide more opportunities for students to devise solutions and problem solving when addressing geographical issues like sustainability.*
There is very little opportunity for this in the current course.	*More frequent project based learning, many opportunities in geography.*

Mathematics

Describe one way in which you have successfully integrated design thinking for your students.	**Describe an example of how you could improve the use of design thinking**
Giving them a problem based on a real life situation ex- designing a bridge that will meet the cost, traffic, and other infrastructural requirement of the city.	*Realiza domina evaluación al finalizar el proceso*
Relate the topics to real life situations and encourage the students to identify the problem, find a way to formulate it, write the steps that will allow to solve it, and check if the answer makes sense.	*A common design thinking framework as part of the curriculum guide, used as an assessment tool by the IBO for*

	deliberately guiding students and evaluating work
Well, in some sections like proving, students would need to decide about method and starting point, and how to develop their idea; in their IA they need to have a sketch of their plan/design and computational thinking skills.	*I could encourage group work.*
By introducing the concept of design thinking and encouraging student to prepare a outline of the problem solving process and reasoning. The IA in mathematics is a good example of design thinking.	*Si los proyectos fueran evaluados curricularmente, con peso en la nota final de alumno seguro que se mejoraría,*
Students formulate problem statements and find their solutions while working on their IAs and EEs. For example while using function modelling, they find an approprite model, test it and use it to future predictions.	*Throwing more problems where students have to find a solution to a real life situation.*
In mathematics, problem-solving is a step by step process and these small steps solve a chalenging real-life application problem. *Usually, we start with the prior knowledge and take them to the new concepts.*	*HACER QUE LOS ESTUDIANTES REALICEN PROYECTOS DE DISEÑOS PARA SATISFACER LA NECESIDAD DE SU LOCALIDAD.*
Encouraging them to incorporate it in their Exploration as it makes it more personal and these are often more interesting and successful to read.	*Realizando una evaluación al finalizar él proceso*
Design thinking is embedded through teaching style which gives somes facts and encourages the development of skills and application of previous knowledge to build up understanding. This will be very important for the Paper 3 style.	*I incorporate design thinking in most of my lessons but yes I would like to improve by assigning more explorations which will require group tasks, investigation, and a concrete synthesis process.*
It is still a work in progress. I cannot say that I have successfully integrated DT in any of my courses with any degree of consistency. I can say that I have found DT to be helpful as a springboard or catalyst when starting new units.	*More application and problem solving inquiry questions or investigations*
Having students predict what shape/function will be plotted when measuring the height of a seat moving around a Ferris Wheel. Then determining what will change in the shape when different things about the Ferris Wheel are changed (height, speed, etc).	*By including activities involving exploration and investigations.*
I don't believe that I have successfully integrated design thinking for my DP students.	*Se lograría mediante el trabajo colaborativo entre estudiantes permitiendo el mejor desarrollo de la creatividad; implementando ademàs la*

	bùsqueda de soluciòn a problemas enfocados en la vida cotidiana.
Cuando forman la vinculación de la Matemática con ejemplos de la vida cotidiana, ellos construyen el pensamiento.	*ask students to design a paper of questions including some concepts.*
I ask students to come up with similar types of questions that they have come across and integrate many topics in a typical question that they make.	*Most problems we do in class are not open-ended because preparing for IB exams does not require much of this type of thinking.*
I have made my learning to design learning materials which we used in studying and comprehending geometry. Things like the pyramids, prisms and cuboids. This impacted learning positively because the learners where able to learn from visibility.	*By designing such assignments to be done during regular classroom teaching(apart from IAs and EEs),in which students make attempts for design /find their solutions to a given problem, verify it and use it for further analysis.*
Cuando se investiga alguna palabra o contenido para la solución de una situaci´n problemática.Luego se esquematiza o grafica.	*Now there will be time dedicated through the "toolkit" in the new Maths courses it will be possible to spend more time on this, with deeper analysis as to the modelling process.*
Con los conceptos de solución de problemas de optimización, razón de cambio y razones relacionadas, se revisan problemas en diferentes contextos y se plantea investigaciones para que estudiantes exploren posibles soluciones.	*Creating a number of questions which require a knowledge of the structure of the Mathematics learnt and application of it to find patterns and develop equations and expressions to describe the patterns, and to answer specific questions.*
The writing of the IA is essentially a design thinking process to begin with. THen computational thinking is a part of the IA.	*When teaching modeling. Also when using the geogebra software to teach calculus.*

Physics

Describe one way in which you have successfully integrated design thinking for your students.	Describe an example of how you could improve the use of design thinking

more group projects like the group 4	*More emphasis on improving and refining designs, however pressure on time prevents this happening often.*
Electricity and Magnetism unit ... students design circuit systems for a variety of different tasks.	*Including more project based learning.*
When studying impulse using recycled materials to design a 'crumple zone' for a trolley rolling down a slope. These were then tested and compared in terms of how successful they were and analysed in terms of impulse.	*By including more practical based questions.*
I ensure that students come up with their innovative ideas to analyse the concept and demonstrate the application.	*Use of more collaborative problem solving approaches within each class to solve practical problems in their own environment. It's a good way to flip the classroom and have them apply their learning in a safe environment.*
Aunque el pensamiento de diseño como tal no se ha implementado en el PD que actualmente se imparte en nuestra institución, puedo comentar que al realizar el proyecto de grupo 4 se aplica los conceptos inherentes a este modelo.	*En el transcurso de las clases habituales no es fácil (lo es más en las investigaciones y prácticas). Por ejemplo haciéndoles preparar y explicar un experimento a modo de experiencia de cátedra. O preparando un examen para que ellos mismos repasen.*
Take few concepts where there can different ways of reaching the solution. So students discuss and arrive at more applicable and relevant solution.	*Looking at the implications of the IA, prac investigations etc. Use of outside sources to experience new applications and innovations.*
In Physics lab work, IA and EE works. In problem solving challenges throughout the course...	*To improve design of the experiment methods based on apparatus availability.*
Development of IA and EE projects that are open ended and as far removed from a basic experiment as possible.	*Maybe more collaboration with other students, schools can help*
I look for more input methods and designing in terms of Internal Assessment and Extended Essay wise for data presentation and analysis.	*If the IB physics course had an engineering element where there was a project for them to apply the physics and design something, then their design thinking would be improved.*

Students design their own investigations for their IAs. They work collaboratively for Group 4 projects.	*Add more labs as well as encourage the students to complete reflections on the lab. The labs they do need to be in increasing order of demand. For this a well thought scheme of work for physics lab course for DP program needs to be established,*
open ended investigations in preparation for the internal assessment which is very much a case of application of design thinking in the group 4 scenario.	*Real-world problems are given to students and they will need to design their own labs experiments to discover and understand content. The students will develop their own driving questions to investigate ways to share their learning.*
In terms of designing for others or designing for a user, physics doesn't do that. However, the students do have to do design labs once a semester, which requires them creatively thinking of procedures and improving upon the procedures.	*We should collaborate with Design technology department to deepen the understanding of concepts which could be shown through the models made in design studio and explain the design that they have adopted based on the theory studied in classes.*
Group 4 project	*Enfocándolo desde los componentes conceptuales que nos están brindando, para completar un ciclo coherente.*
Para los diferentes trabajos usamos vídeos comentamos la información y tomamos las aplicaciones establecemos relaciones con los datos alli disponibles y vamos creando todos los nexos que son evidentes para el tema asignado	*Introduce design thinking as a concept more explicitly and carry out a lab work with the aim to develop design thinking skills.*
About finding the topic of IA *revision of the topic*	*En primer lugar observar un problema que puede tener una solución de manera creativa mediante la indagación y propuesta de prototipos a escala por medio de la comprobación en los laboratorio y campo de acuerdo a la propuesta y diseño experimental.*
En la resolución de problemas, los estudiantes trabajan de manera colaborativa y resuelven de manera creativa.	*I could guide students purposely to get an opportunity to explore and develop their inter and intrapersonal skills. I may*

	provide opportunities that allow for teamwork, collaboration and leadership skills to be exercised.
This year, I have not prioritized design thinking in my course, although next year this will be more of a priority for me in the course.	*Using problem based approaches.*
labwork in the internal assessment. In general the problema with integrating design thinking in the curriculum is that the student lack theoretical background to make an adequate analysis of open ended problems	*Carrying out more open-ended experiments, where students are allowed to design their own methods and choose equipment. Unfortunately, this is impossible due to time limits, having to go through the whole content of the DP course*
Not very well as most IB schools are not aware of this. The subject guides do not include this.	*By having more time for open ended problems*
In their IA investigation students have to design their experiment based on the Research question and the topic keeping in view of the limitations of the equipment available in the lab and the controlled variables.	*Mediante un reto en donde diseñen un prototipo para resolver un problema de un robot tipo FIRST que lance objetos en tiro parabólico.*
Los estudiantes se encargaron de construir una montaña rusa que fuese capaz de permitir a una canica dar dos vueltas en bucle según condiciones específicas iniciales y finales.	
I don't, I teach Physics, please stop this and let teachers teach rather than telling us how to teach, we don't need another fad. Just add's more to a course that is way too content heavy for the time we have. Let us teach, stop re-inventing the wheel.	

Integrating CT

Chemistry

Describe one way in which you have successfully integrated computational thinking for your students.	Describe an example of how you could improve the use of computational thinking

There are many examples of this; anywhere where a standard way can be used to think the way through a problem.	*Remove some knowledge content to allow student time to practice it get students to develop ways to create it themselves.*
Computational thinking was useful in generalizing the trends into rules, especially for trends of chemical bonding strength, intermolecular interactions and physical properties of substances.	*Better use of technology in the classroom that shows the students how solutions may be simulated.*
Students have worked on internal assessment using different database. They use simulation while doing various topics in chemistry to have better understanding of real world.	*Students need to provide IA ideas and procedures in a computational thinning.*
Computational thinking is incorporated by assigning work that requires the use of software in the completion of the task and cannot be completed effectively without the use of computers.	*Giving them topics and asking them to design their own practical on it. It may be a study or an investigation.*
also through teaching kinetics, rate of reaction. students are asked to collect data and find correlations through mathematical modeling	*Using popular chemistry software to design and explain the structure of a compound and how elements interact with each other using animations.*
While solving numericals to determine the value of equilibrium constant , students devise an algorithm (steps) to calculate the constant .	*Con mayores instancias de desafío.*
I have not managed to amalgamate Computational thinking in the course. Other than creating questions which tests their application skills in Chemistry not much.	*Stoichiometry problems are typical ones.*
Using excel to present information, using of data loggers to read temperature and pH, and analysing data.	*Be careful of giving out cues as questions*
El uso de simulaciones permite a los estudiantes un acercamiento a la realidad de algunos fenómenos que son difíciles de evidenciarlos, directamente entonces apoyados de simulaciones podemos entender y facilitar el aprendizaje de situaciones complejas.	*Think about how we use equations more readily and maybe how students could figure out the relationship between variables on their own? Integrate scratch programing or inferential statistics?*
Je n'enseigne pas les algorithmes et n'y fait pas référence mais j'enseigne l'utilisation des tableurs pour le traitement de données.	*Due to time restrictions I had to arrange the laboratory experiments and student presentation in groups. Individual experience would help the students to reflect better.*

Computer Science

Describe one way in which you have successfully integrated computational thinking for your students.	Describe an example of how you could improve the use of computational thinking
Same answer as when asked about integrating design thinking. There is no way to teach Computer Science (Option D: Object-oriented programming (OOP)), without integrating computational thinking in the classes.	*I dont see any. I suggest to keep the IA as it is, but maybe put less pressure on the documentation. This improved a lot in the new guide, but still, students spend more time with documentation than with programming.*
Programming is all about computational thinking.... Making the students solve tricky problems helped me in integrating computational thinking.	*By giving insight to learning computing strategies to give software solution to algorithm development*
This is a computer science course... There is a lot of algorithmic and problem-solving in the curriculum.	*When CS students join a group 4 project there should be some part of the project that involves CT, this would require some "adjusting" of G4project aims and requirements but should be possible.*
Al momento de resolver un problema se menciona en cada proceso donde se encuentra inmerso las etapas del pensamiento computacional para que ellos puedan comprender y aplicar en futuros ejercicios prácticos	*Reffering to past papers it can be similar to paper 1 expressing results of a part of algorithm or completing an algorithm so as to achieve an expected result*
By giving student over 150 assessed Java tasks that ask for computational thinking to be applied. Also pseudo code tasks for tests/exams.	*Self learn in different platforms and find a way to relate with students view*
Planteo, análisis y discusión de situaciones nuevas. Planteo de soluciones usando distintas herramientas, justificando su eficiencia y eficacia, proponiendo mejoras y analizando la complejidad algorítmica en cada caso, individual y grupalmente.	*By having a mixture of physical and theoretical problems for students to apply it to.*
Data Representation chapter and programming units	*Include a code lab that addresses small real life projects. Possibly addressing broader activities like robotics and machine learning to get a basic understanding of applications of computer science in our every day life.*

Design Technology

Describe one way in which you have successfully integrated computational thinking for your students.	Describe an example of how you could improve the use of computational thinking
Computational Thinking is handled by ICT professionals	*La verdad es que no estoy seguro. Es algo en lo que tengo que trabajar para mejorar el próximo año.*
Este año apenas he integrado este tipo de pensamiento. Es un área de mejora para el próximo curso.	*We are not experts in ICT so the coding units are limited (Grade 8) the school does not offer ICT so Design and Design Technology are the sole providers of these skills. PD is limited in these areas locally.*
Very little. If it was built into the curriculum, we would do more.	*Hands-on Training*
Aún no hemos comenzado con esta parte, pero la idea es que el curso que viene (2º Bachillerato) desarrollamos habilidades de proyección en 3D que puedan aplicar a sus proyectos de diseño.	*Through interdisciplinary collaborative projects, resources, field trips and/or specifically focused projects. (Perhaps.)*
Various coding projects at almost every year level.	*More use of flow charts in the planning stages for manufacture, maybe a formal Gant Chart with correctly calculated timings.*
I have integrated it trough programs like Hour of Code but there is very little computational thinking in Design Tech	*I need to further understand the concept of 'computational thinking' in order to improve*
I don't think I have successfully integrated unless you consider TynkerCAD a way to write algorithms.	*IA- Criterion A recording user survey and developing info graphics for research purposes. Criterion B developing ideas Criterion E commercial production calculations.*
By showing the students designs on paper and the actual designs on programs like Fusion 360 or Techsoft 2D design. They draw by hand and then when they use	*With less content to cover in the DP program, more time may be allocated to developing such necessary skills.*

computers they can see the beneifits and time saved in using computers.	
Los alumnos han tomado clases con diversos programas de diseño en 2D (Illustrator) y en 3D (Catia, Space Claim)	

Geography

Describe one way in which you have successfully integrated computational thinking for your students.	Describe an example of how you could improve the use of computational thinking
I don't think I have.	*Con la capacitación docente, ya que requerimos un mayor conocimiento y adecuación al respecto, así como aulas equipadas en forma efectiva.*
I can't describe any.	*Giving more practices to students, having field trips to some areas affected by a given events.*
There is very little opportunity for this in the current course.	*I think a starting point would be to improve my own understanding. I would not be confident in guiding anyone else through using this technique.*
	Again I am struggling to think of ideas on other areas of the course where this type of thinking could be developed. I would like to have more practical examples.
The parts of the syllabus that are open to calculations of sorts - correlations, testing hypotheses and then rethinking the hypotheses and finding new matters to correlate.	*Again, time, personal skill improvement, perhaps collaboration with other teachers of the subject on how to integrate this into the busy IB syllabus content.*
Uso de TICS para un desarrollo de clases animadas que involucren satisfactoriamente al estudiante.	*Modelling for weather and geophysical hazards (prediction and monitoring)*
On the IA and during model analysis, students must use computational thinking skills to correctly interpret what they see. Furthermore, students use Spearman's Rank to	*Atelier de cartographie en classe sur le temps du TI*

demonstrate the strength of the correlation between variables.	
working with maps of different scales, labeling diagrams, to spot the patterns, when we talk about methods of an experiment as an algorithm	*I am not sure.*
Limited - except in the internal assessment when, depending on interests of the student, greater use is made of computer abilities in excel. Not really my integration, but driven by student competency and interest	*Con capacitación docente adecuación de aulas*

Mathematics

Describe one way in which you have successfully integrated computational thinking for your students.	**Describe an example of how you could improve the use of computational thinking**
In mathematics, students have to formulate different things to come up with a solution to a problem, especially for open-ended problems if they are in groups they got this opportunity to develop their skills.	*Sistematizando procesos de resolución de problemas y situaciones complejas*
Online calculators and different software are used to solve mathematical problems.	*Mathematics is about "problem solving" therefore plenty possibilities to incorporate CT. I guess there is always a space for an improvement through allocating more time where students work independently on relevant to them problems.*
Providing open problems that may need different mathematical concepts to be applied together.	*The analytical thinking process I described in my previous post can be reviewed and enhanced based on the specific students who are using it*
Computational thinking is involved in problem solving exercises in the context and in interdisciplinary areas.	*By connecting mathematical concepts to solve real world problems, students not only develop their computational skills they also develop their social and communication skills while working in groups.*
Some of the investigations done in class gave them an opportunity to use computational thinking.	*Desarrollando algoritmos simples, pero traducidos a un lenguaje computacional*

	con un interfaz gráfica amigable como puede ser visual c++
In many cases, repetitive math problems can be coded into Excel. I have my students do this. If they can teach a computer to find eigenvalues and eigenvectors based off of an initial matrix, they really understand the process.	*uso diario de graficadores de modelos.*
Once you have the technology in place, it is time to begin integrating computational thinking into lesson planning. You should begin to consider different ways your students can work on problem-solving while utilizing technology.	*Incorporate many of the modeling ideas and problems posed from past Moody Challenges. Class could easily be broken up into groups of 5 or 6. Time would need to be set aside to introduce the finer points of modeling.*
For each topic they have a basic algorithm to identify the topic being tested within a question, to identify what formulae may be of use and the various steps they should consider trying in order to answer the question.	*Para mejorar debería los alumnos tener disponibilidad de computadores o herramientas tecnológicas con iguales características para hacer más fácil la comunicación de las instrucciones y el desarrollo de alguna actividad*
Computational thinking we have integrated in a topic called numerical techniques. For this topic students adopted computational technique to calculate the larger values in the iteration technique.	*Learn how to use mathematical applications such as geogebra for more than just graphing as well as learning to use correct mathematical terminology on a laptop/device.*
When working out the formulas for sequences or binomial expansion. Also in trigonometry when working equations with the multiples of pi/2 3pi/2 ans such stuff. Also when working in derivatis and using a loop of chain rules.	*Make what I already do more formal / structured and give it to them towards the end of a topic. Start addressing this skill more in the lower years.*
El pensamiento computacional es desarrollado, particularmente en relación a la elaboración de cronogramas y ejecución de actividades por etapas en el trabajo que hacemos en relación a la Exploración Matemática.	*Taking the longer questions from exams, particularly paper 3 style questions, and looking at the overall aim, and seeing how it can be (has been) broken down to make this manageable. It is also a necessary skill for the Mathematical Explorations.*
Generalmente el uso de la calculadora o de algún programa computacional como una herramienta de apoyo a la solución de los problemas	*Leaving more open ended questions. This is difficult because of timing.*
No se lo ha hecho en gran medida pero de alguna manera se lo ha involucrado en las CPG.	*Tal vez insertando más actividades de resolución de problemas que deban ser*

	realizadas por etapas a ser definidas por los alumnos.
En el uso de medio informáticos para resolver problemas de matemática y representar gráficamente, el uso de goegebra en ecuaciones de segundo grado de cónicas.	*Continuous practice in designing questions that deliberately uses computational thinking and gradually improving from lesson to lesson through reflective thinking.*
In mathematics, students have to formulate different things to come up with a solution to a problem, especially for open-ended problems if they are in groups they got this opportunity to develop their skills.	*Give more real life examples*
Online calculators and different software are used to solve mathematical problems.	*For example to fine point of intersection of two graphs an solving any equation.*
Providing open problems that may need different mathematical concepts to be applied together.	*Quizá combinando o interconectando las áreas Matemática e Informática, practicando la programación del método de Gauss por ejemplo.*
Computational thinking is involved in problem solving exercises in the context and in interdisciplinary areas.	*Not sure*
Some of the investigations done in class gave them an opportunity to use computational thinking.	*facilitar los programas matemáticos*
Once you have the technology in place, it is time to begin integrating computational thinking into lesson planning. You should begin to consider different ways your students can work on problem-solving while utilizing technology.	*If students had the opportunity to learn some programming or by using spreadsheet tools such as excel, this allows students to practice use computational thinking in solving problems.*
For each topic they have a basic algorithm to identify the topic being tested within a question, to identify what formulae may be of use and the various steps they should consider trying in order to answer the question.	
Computational thinking we have integrated in a topic called numerical techniques. For this topic students adopted computational technique to calculate the larger values in the iteration technique.	
When working out the formulas for sequences or binomial expansion. Also in trigonometry when working equations	

with the multiples of pi/2 3pi/2 ans such stuff. Also when working in derivatis and using a loop of chain rules.	
El pensamiento computacional es desarrollado, particularmente en relación a la elaboración de cronogramas y ejecución de actividades por etapas en el trabajo que hacemos en relación a la Exploración Matemática.	

Physics

Describe one way in which you have successfully integrated computational thinking for your students.	Describe an example of how you could improve the use of computational thinking
I haven't integrated Computational thinking	Teaching the skill in a more generalised way and emphasising how the skill is used across the course i.e. not just suvat, errors... but using the phrase computational thinking to emphasise the commonality of approach.
Writing their own simulation for half-life.	I would like to incorporate the skill in all the concepts, some time I feel that is challenging
The application concepts of subject ensure their computational thinking skills	Including some more numerical of higher thinking level.
Use in investigations	Being more purposeful in my teaching of Geogebra simulations and integrating them more into my classroom.
En la investigación de la monografía se recurrió al planteo del problema, el diseño de un algoritmo de solución y luego ir depurando las información adecuada y los módulos de la simulación de la solución al problema planteado.	Multi-step design labs are still limited in scope. If I had them run the experiments for longer and got more involved in them, then it would be more computational. The EEs in physics are more like this.

Every concept where calculations are involved, problems are taken and given for practising.	Plotting graphs using Ms.Excel and Geogebra.
Les travaux expérimentaux permettent de bien utiliser l'outil informatique pour le traitement des données et l'établissement de rapport.	As a teacher, I need to make myself more able in computational thinking so I can design my course in a way that students incorporate Computational Thinking into their Physics problem solving.
Development of time and data management strategies for IAs and EEs. Allowing pupils to plan and execute using holistic view with specific skills applied selectively and appropriately.	By generalizing and transferring this problem solving process to a wide variety of problems
In data processing for lab reports and to visualize complex phenomena using simulations.	Que los estudiantes elaboren en forma de algoritmo los pasos que siguen para resolver una situación problemática.
problem solving activities in class	Integrate more examples of computational experiments: Computational Physics
It comes in every toolkit or signpost towards problem solving that we encounter. If we take a step by step approach then we are effectively at the beginning of computational thinking	So little time...
In my idea, computational thinking requires looking at data and adjusting a design or a variable. This is done in the design labs with the students. They analyze data and then optimize their designs.	ejemplo en la utilización de distintos software para tener variables que se necesitan, pero seria bueno tener una asignatura de algoritmo o cualquier tipo de lenguaje computacional construyendo el algoritmo necesario.
Al hacer uso de los simuladores que traen ejercicios para ser resueltos en clase	Comprendiendo los procesos de elaboración del medio - sensores o simuladores en función a los modelos matemáticos que se usan para la entrega de resultados
Interpretando cualquier correlación entre dos magnitudes	By deliberately designing projects for students to carry out. Students should be equally involved in the design of such projects.
In IA, data analysis part , solving open ended problems	incorporating the use of computer programs such as Mathematica, Maple

	or Wolfram Alpha more. Giving assignments that would require them to create a worksheet within one of those programs
Using simulations and databases (from NASA) for students to collect data and make a conclusion	Using my previous example, I could have students create a flow-chart for solving the SUVAT equations that follows an algorithmic process using if-then statements.
En la resolución de problemas.	decicating more time to practising the procedure
Con cierta frecuencia deben elaborar organizadores visuales sobre los temas, con lo que tienen que pensar en las posibilidades que tienen para el uso de algún software. también elaboran algunos algoritmos para la resolución de problemas.	Puedo incluir más el uso de apps y softwares en el salón para aportar al aprendizaje
One way is by answering the numericals which can be addressed in more than one way. All the structured questions require computational thinking . Also NOS questions have good openended solutions .	Progressively have students develop their problem-solving skills with problems they have not seen before.
Uso de simulaciones y moderaciones a través de softwares como Logger, Tracker, Geogebra entre otras.	To model some physical phenomenas like projectile motion of football during the real football match.
Se debería integrar mediante ejercicios prácticos donde se aplique la indagación, análisis, buscar soluciones y tener conclusiones precisas.	considero que es empleado en su mayoría en el área de matemáticas
Cuando presento las diapositivas en infocus, ellos observan la presentación y muy buena que el docente realizó por lo cual ellos se sienten feliz al ver aquellas imagenes.	Intergrar y optimizar una dinámica de trabajo permanente y de contacto con tareas con ayuda tutorial para desarrollarla es decir guiar la indagacion y dar los puntos claros para llegar a la enseñanza aprendizaje.
Most problem solving and practical work has this as an integral part more specifically python or MSexcel modelling for physicists	

Fostering Computational & Design Thinking in the IB DP, MYP, and PYP

Appendix F
Programme & Teacher Surveys

Appendix F. Final Surveys Administered

DP Survey

DIPLOMA PROGRAMME TEACHER SURVEY

A. YOU AND YOUR SCHOOL

1. What IB programmes are running at your school?
    a. Primary Years Programme (PYP)
    b. Middle Years Programme (MYP)
    c. Diploma Programme (DP)
    d. Career-related Programme (CP)

2. Please select your main role.
    a. A DP teacher
    b. A DP Programme Coordinator

3. How many years of experience do you have in each of the following?
    Please enter a whole number.
    a. In your current role: _______
    b. Working with the IB programme(s), in any role: _______
    c. Being an educator, including non-IB experience: ________

4. Please select <u>one</u> course that you teach from the following options. You should think of this course only when answering the rest of the questions.
    a. Chemistry
    b. Physics
    c. Geography
    d. Computer Science
    e. Design Technology
    f. Mathematics Applications and Interpretation
    g. Mathematics Analysis and Approaches

5. How many students do you have in a typical course?
    Please enter a whole number.

    ______

6. What do you think about Design Thinking and Computational Thinking?

B. DESIGN THINKING AND COMPUTATIONAL THINKING WITHIN YOUR TEACHING

1. Please indicate your level of agreement with the following statements about computational thinking.

	I have a strong understanding of…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	… the definition of computational thinking							
b.	… how computational thinking can be incorporated into my courses.							

	Computational thinking…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	... is important for 21st century learners							
b.	… is a current priority in my school's DP							
c.	… should be taught mainly in computer courses.							

2. Please indicate your level of agreement with the following statements about design thinking.

	I have a strong understanding of…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	… the definition of design thinking							
b.	… how design thinking can be incorporated into my courses.							

	Design thinking…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	... is important for 21st century learners							
b.	... is an important priority for IB courses in my school's DP							
c.	…is a current priority in my school's DP							
d.	… should be taught mainly in design courses.							

C. HOW YOU INTEGRATE DESIGN THINKING AND COMPUTATIONAL THINKING IN YOUR TEACHING

The current research project has adopted the following "working definitions":

Design thinking: Design thinking engages learners in a process through which they collaboratively develop creative solutions for open-ended, unstructured problems. Creative, user-centered approaches are at the heart of design thinking, requiring students to develop skills in creativity, empathy, systematic thinking, and to communicate in the language of design, while progressing through iterative cycles of design, building, testing, and redesign. Fundamental processes underlying design thinking are as follows: A) Inquiring and analyzing; (B) Developing ideas; (C) Creating the solution; (D) Evaluating; E) Iterating on the design

Computational thinking: Computational thinking refers to a set of cognitive processes underlying a particular form of problem solving and reasoning. In addressing open-ended problems, students rely on CT whenever they formulate the problem in such a way that its solutions can be represented as algorithms that can be worked through either by computers or humans. Complex problems can be decomposed into simpler ones, whose solutions can then be assembled together to solve the original problem. Such algorithmic solutions often require the use of abstract representations of the problem (e.g., models, equations and simulations) as well as the organization and analysis of data. Once the algorithms have generated some solution, students iteratively check the outcome (i.e., debugging) and improve their solution. While this process underlies most computer programming, the strategies, patterns, and techniques of computational thinking can be applied to a wider class of problems and areas of daily life (e.g., coordinating a complex schedule or organizing our daily routines to be more efficient).

1. Please indicate your level of agreement with the following statements on how the course you selected above (Chemistry, Physics, Geography, Computer Science, Design Technology, Mathematics Applications and Interpretation, OR Mathematics Analysis and Approaches) **may support design thinking.**

	Overall, the course…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	... emphasizes design thinking							
b.	... reflects current teaching and learning practices concerned with design thinking							
c.	… facilitates students to deepen their understanding of design thinking.							

2. Please indicate your level of agreement with the following statements on how the course you selected above (Chemistry, Physics, Geography, Computer Science, Design Technology, Mathematics Applications and Interpretation, OR Mathematics Analysis and Approaches) **relates to design thinking.**

	The course provides opportunities for students to become familiar with the…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree
a.	... key concepts of design thinking						
b.	… applications of design thinking						
c.	… skills required for design thinking						
d.	... design thinking methodology (eg, problem solving).						

3. Please indicate your level of agreement with the following statements on how the course you selected above (Chemistry, Physics, Geography, Computer Science, Design Technology, Mathematics Applications and Interpretation, OR Mathematics Analysis and Approaches), **may support computational thinking (CT)**

	Overall, the course…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	... emphasizes computational thinking							
b.	...reflects current teaching and learning practices concerned with computational thinking							
c.	…facilitates students to deepen their understanding of computational thinking.							

4. Please indicate your level of agreement with the following statements on how the course you selected above, (Chemistry, Physics, Geography, Computer Science, Design Technology, Mathematics Applications and Interpretation, OR Mathematics Analysis and Approaches), **relates to computational thinking.**

	The course provides opportunities for students to become familiar with the…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree
a.	... key concepts of computational thinking						
b.	… applications of computational thinking						
c.	… skills required for computational thinking						
d.	... computational thinking methodology (eg, problem solving).						

5. Please rate the amount of content in the course you selected above, (Chemistry, Physics, Geography, Computer Science, Design Technology, Mathematics Applications and Interpretation, OR Mathematics Analysis and Approaches) **that connects to each of the following.**

	Far too little	Too little	About right	Too much	Far too much
Computational thinking					
Design thinking					

6. Please rate the level of challenge that the course you selected above (Chemistry, Physics, Geography, Computer Science, Design Technology, Mathematics Applications and Interpretation, OR Mathematics Analysis and Approaches) **provides for students in the DP.**

	Far too easy	Too easy	About right	Too challenging	Far too challenging
Computational thinking					
Design thinking					

D. HOW DESIGN AND COMPUTATIONAL THINKING ARE INTEGRATED ACROSS IB PROGRAMMES

This final section will ask you to respond to seven open-ended questions about integrating design and computational thinking in your teaching and course designs.

1. Please describe one way in which you have successfully integrated design thinking for your students.
2. Please describe an example of how you could improve the use of design thinking in your teaching.
3. What are some obstacles that limit your ability to include design thinking in your course?
4. Please describe one way you have successfully integrated computational thinking for your students.
5. Please describe an example of how you could improve the use of computational thinking in your teaching?
6. What are some obstacles that limit your ability to include computational in your course?
7. Can you make any suggestions about how student thinking processes like design thinking and computational thinking could be better supported across the Diploma Programme?

MYP Survey

MIDDLE YEARS PROGRAMME TEACHER SURVEY

A. YOU AND YOUR SCHOOL

1. What IB programmes are running at your school?
    a. Primary Years Programme (PYP)
    b. Middle Years Programme (MYP)
    c. Diploma Programme (DP)
    d. Career-related Programme (CP)

2. Please select your main role.
    a. A MYP teacher
    b. A MYP Programme Coordinator

3. How many years of experience do you have in each of the following?
    Please enter a whole number.
    a. In your current role: ________
    b. Working with the IB programme(s), in any role: ________
    c. Being an educator, including non-IB experience: ________

4. Please select one course that you teach from the following options. You should think of this course only when answering the rest of the questions.
    a. Design
    b. Sciences
    c. Individuals and Societies
    d. Mathematics

5. How many students do you have in a typical course?
    Please enter a whole number.

_____

6. What do you think about Design Thinking and Computational Thinking?

B. DESIGN THINKING AND COMPUTATIONAL THINKING WITHIN YOUR TEACHING

1. Please indicate your level of agreement with the following statements about computational thinking.

	I have a strong understanding of…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	… the definition of computational Thinking							
b.	… how computational thinking can be incorporated into my courses.							

	Computational thinking…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	... is important for 21st century learners							
b.	… is a current priority in my school's MYP							
c.	… should be taught mainly in computer courses.							

2. Please indicate your level of agreement with the following statements about design thinking.

	I have a strong understanding of…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	… the definition of design thinking							
b.	… how design thinking can be incorporated into my courses.							

	Design thinking…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	... is important for 21st century learners							
b.	... is an important priority for IB courses in my school's MYP							
c.	…is a current priority in my school's MYP							

d.	… should be taught as a stand alone design course as it is in MYP							
e.	…should be integrated in courses other than MYP design.							

C. HOW YOU INTEGRATE DESIGN THINKING AND COMPUTATIONAL THINKING IN YOUR TEACHING

The current research project has adopted the following "working definitions":

Design thinking: *Design thinking engages learners in a process through which they collaboratively develop creative solutions for open-ended, unstructured problems. Creative, user-centered approaches are at the heart of design thinking, requiring students to develop skills in creativity, empathy, systematic thinking, and to communicate in the language of design, while progressing through iterative cycles of design, building, testing, and redesign. Fundamental processes underlying design thinking are as follows: A) Inquiring and analyzing; (B) Developing ideas; (C) Creating the solution; (D) Evaluating; E) Iterating on the design*

Computational thinking: *Computational thinking refers to a set of cognitive processes underlying a particular form of problem solving and reasoning. In addressing open-ended problems, students rely on CT whenever they formulate the problem in such a way that its solutions can be represented as algorithms that can be worked through either by computers or humans. Complex problems can be decomposed into simpler ones, whose solutions can then be assembled together to solve the original problem. Such algorithmic solutions often require the use of abstract representations of the problem (e.g., models, equations and simulations) as well as the organization and analysis of data. Once the algorithms have generated some solution, students iteratively check the outcome (i.e., debugging) and improve their solution. While this process underlies most computer programming, the strategies, patterns, and techniques of computational thinking can be applied to a wider class of problems and areas of daily life (e.g., coordinating a complex schedule or organizing our daily routines to be more efficient).*

1. **Please indicate your level of agreement with the following statements on how the course you selected above** (Sciences, Individuals and Societies, OR Mathematics) **may support design thinking.**

	Overall, the course…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	... emphasizes design thinking							
b.	...reflects current teaching and learning practices concerned with design thinking							
c.	… facilitates students to deepen their understanding of design thinking.							

2. **Please indicate your level of agreement with the following statements on how the course you selected above** (Sciences, Individuals and Societies, Mathematics, or Design) **relates to design thinking.**

	The course provides opportunities for students to become familiar with the…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree
a.	...key concepts of design thinking						
b.	… applications of design thinking						
c.	… skills required for design thinking						
d.	... design thinking methodology (eg, problem solving).						

3. Please indicate your level of agreement with the following statements on how the course you selected above (Sciences, Individuals and Societies, Mathematics OR Design) **may support computational thinking (CT).**

	Overall, the course…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	... emphasizes computational thinking							
b.	...reflects current teaching and learning practices concerned with computational thinking							
c.	… facilitates students to deepen their understanding of computational thinking.							

4. Please indicate your level of agreement with the following statements on how the course you selected above, (Sciences, Individuals and Societies, Mathematics OR Design)**, relates to computational thinking.**

	The course provides opportunities for students to become familiar with the…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree
a.	... key concepts of computational thinking						
b.	… applications of computational thinking						
c.	… skills required for computational thinking						
d.	... computational thinking methodology (e.g., problem solving).						

5. **Please rate the amount of content in the course you selected above** (Sciences, Individuals and Societies, Mathematics OR Design) **that connects to each of the following.**

	Far too little	Too little	About right	Too much	Far too much
Computational thinking					
Design thinking					

6. **Please rate the level of challenge that the course you selected above** (Sciences, Individuals and Societies, Mathematics OR Design) **provides for students in the MYP.**

	Far too easy	Too easy	About right	Too challenging	Far too challenging
Computational thinking					
Design thinking					

D. HOW DESIGN AND COMPUTATIONAL THINKING ARE INTEGRATED ACROSS IB PROGRAMMES

This final section will ask you to respond to seven open-ended questions about integrating design and computational thinking in your teaching and course designs.

1. Please describe one way in which you have successfully integrated design thinking for your students.
2. Please describe an example of how you could improve the use of design thinking in your teaching.
3. What are some obstacles that limit your ability to include design thinking in your course?
4. Please describe one way you have successfully integrated computational thinking for your students.
5. Please describe an example of how you could improve the use of computational thinking in your teaching?
6. What are some obstacles that limit your ability to include computational thinking in your course?
7. Can you make any suggestions about how student thinking processes like design thinking and computational thinking could be better supported across the Middle Years Programme?

PYP Survey

PRIMARY YEARS PROGRAMME TEACHER SURVEY

A. YOU AND YOUR SCHOOL

1. What IB programmes are running at your school?
   a. Primary Years Programme (PYP)
   b. Middle Years Programme (MYP)
   c. Diploma Programme (DP)
   d. Career-related Programme (CP)

2. Please select your main role.
   a. A PYP teacher
   b. A PYP Programme Coordinator

3. How many years of experience do you have in each of the following?
   Please enter a whole number.
   a. In your current role: _______
   b. Working with the IB programme(s), in any role: _______
   c. Being an educator, including non-IB experience: ________

4. What student age group do you teach?
   Please select all that apply.
   a. 3-4 years old
   b. 5-6 years old
   c. 7-8 years old
   d. 19-10 years old
   e. 11 to 12 years old
   f. I do not teach in the classroom

5. Do you have any subject or PYP specializations?
   Please select all that apply.
   a. Mathematics
   b. Science
   c. Social Studies
   d. Exhibition Coordination
   e. I have no subject or PYP specializations

6. How many students do you have in a typical class?
   Please enter a whole number.

_____

7. What do you think about Design Thinking and Computational Thinking?

B. DESIGN THINKING AND COMPUTATIONAL THINKING WITHIN YOUR TEACHING

1. Please indicate your level of agreement with the following statements about computational thinking.

	I have a strong understanding of…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	… the definition of computational thinking							
b.	… how computational thinking can be incorporated into my programme of inquiry.							

	Computational thinking…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	... is important for 21st century learners							
b.	… is a current priority in my school's PYP							
c.	... is an important priority for units of inquiry in my school's PYP							
d.	… should be taught mainly in the PYP math scope and sequence							
e.	… should be taught mainly in the PYP programme of inquiry.							

2. Please indicate your level of agreement with the following statements about design thinking.

	I have a strong understanding of…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	… the definition of design thinking							
b.	… how design thinking can be incorporated into my programme of inquiry.							

	Design thinking…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	... is important for 21st century learners							
b.	…is a current priority in my school's PYP							
c.	... is an important priority for units of inquiry in my school's PYP							
d.	… should be taught mainly in focused units of inquiry that deal with design							
e.	…should be integrated within all programmes of inquiry.							

C. HOW YOU INTEGRATE DESIGN THINKING AND COMPUTATIONAL THINKING IN YOUR TEACHING

The current research project has adopted the following "working definitions":

Design thinking: *Design thinking engages learners in a process through which they collaboratively develop creative solutions for open-ended, unstructured problems. Creative, user-centered approaches are at the heart of design thinking, requiring students to develop skills in creativity, empathy, systematic thinking, and to communicate in the language of design, while progressing through iterative cycles of design, building, testing, and redesign. Fundamental processes underlying design thinking are as follows: A) Inquiring and analyzing; (B) Developing ideas; (C) Creating the solution; (D) Evaluating; E) Iterating on the design*

Computational thinking: *Computational thinking refers to a set of cognitive processes underlying a particular form of problem solving and reasoning. In addressing to open-ended problems, students rely on CT whenever they formulate the problem in such a way that its solutions can be represented as algorithms that can be worked through either by computers or humans. Complex problems can be decomposed into simpler ones, whose solutions can then be assembled together to solve the original problem. Such algorithmic solutions often require the use of abstract representations of the problem (e.g., models, equations and simulations) as well as the organization and analysis of data. Once the algorithms have generated some solution, students iteratively check the outcome (i.e., debugging) and improve their solution. While this process underlies most computer programming, the strategies, patterns, and techniques of computational thinking can be applied to a wider class of problems and areas of daily life (e.g., coordinating a complex schedule or organizing our daily routines to be more efficient).*

1. Please indicate your level of agreement with the following statements on how your programme of inquiry may support design thinking.

	Overall, the programme of inquiry…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ I don't know
a.	... emphasize design thinking							
b.	... reflects current teaching and learning practices concerned with design thinking							

c.	… facilitates students to deepen their understanding of design thinking.							

2. Please indicate your level of agreement with the following statements on your programme of inquiry, relating to design thinking.

	Our programme of inquiry provides opportunities for students to become familiar with the…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree
a.	... key concepts of design thinking						
b.	… applications of design thinking						
c.	… skills required for design thinking						
d.	... design thinking methodology (eg, problem solving).						

3. Please indicate your level of agreement with the following statements on how your programme of inquiry may support computational thinking.

	Overall, our programme of inquiry …	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree	NA/ Don't know
a.	... emphasizes computational thinking							
b.	... reflects current teaching and learning practices concerned with computational thinking							
c.	… facilitates students to deepen their understanding of computational thinking.							

4. Please indicate your level of agreement with the following statements on your programme of inquiry, relating to computational thinking.

	Our programmes of inquiry provide opportunities for students to become familiar with the…	Strongly disagree	Disagree	Somewhat disagree	Somewhat agree	Agree	Strongly agree
a.	... key concepts of computational thinking						
b.	… applications of computational thinking						
c.	… skills required for computational thinking						
d.	... computational thinking methodology (eg, problem solving).						

5. Please rate how much attention is given, within your programmes of inquiry, to the following:

	Very little	Not much	About right	Too much	Far too much
Computational thinking					
Design thinking					

6. Please rate the level of challenge that your programme of inquiry provides for students in the PYP.

	Far too easy	Too easy	About right	Too challenging	Far too challenging
Computational thinking					
Design thinking					

D. HOW DESIGN AND COMPUTATIONAL THINKING ARE INTEGRATED ACROSS IB PROGRAMMES

This final section will ask you to respond to seven open-ended questions about integrating design and computational thinking in your teaching and course designs.

1. Please describe one way in which you have successfully integrated design thinking for your students.

2. Please describe an example of how you could improve the use of design thinking in your teaching.

3. What are some obstacles that limit your ability to include design thinking in your teaching?

4. Please describe one way you have successfully integrated computational thinking for your students.

5. Please describe an example of how you could improve the use of computational thinking in your teaching.

6. What are some obstacles that limit your ability to include computational thinking in your teaching?

7. Can you make any suggestions about how student competencies like design thinking and computational thinking could be better supported across the Primary Years Programme?